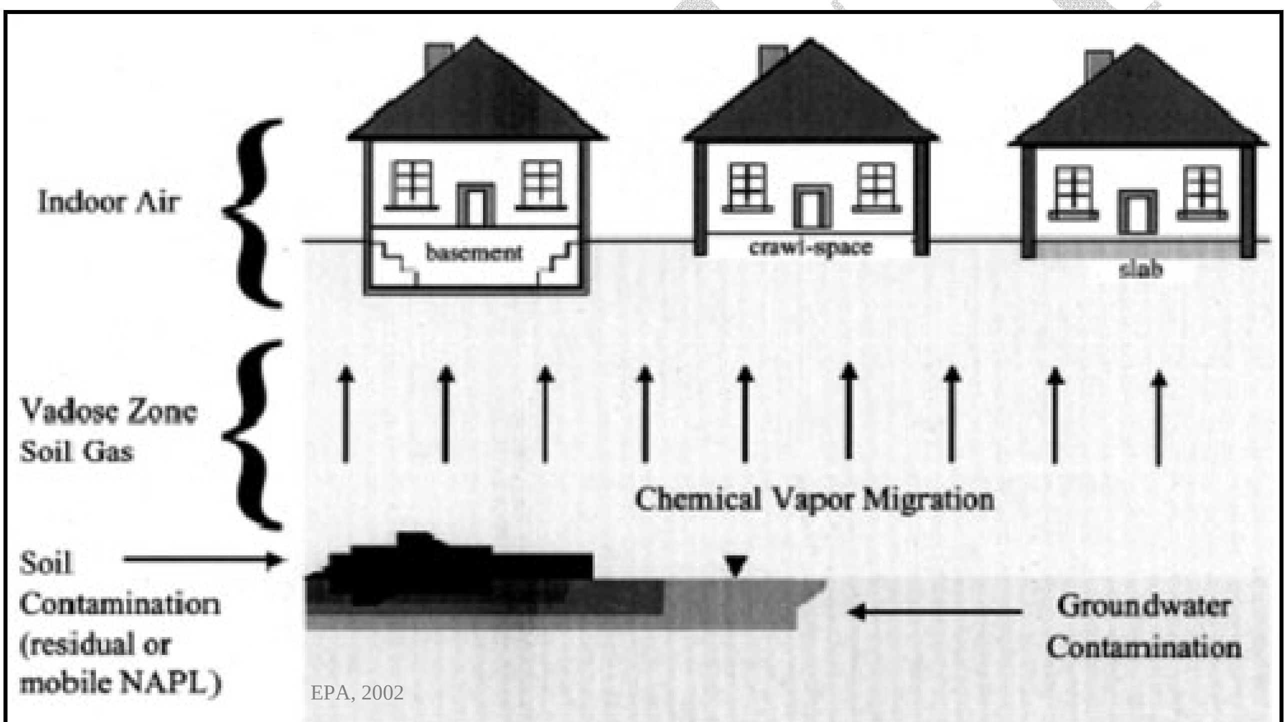
Indiana Department of Environmental Management

Draft Vapor Intrusion

Pilot Program Guidance



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Introduction to IDEM's Vapor Intrusion Guidance

Sites contaminated by volatile organic compounds (VOCs) may present a public health hazard if compounds volatilizing from groundwater, soil or non-aqueous phase liquids (NAPLs) migrate into a building where humans are exposed. The completion of this human exposure pathway from VOCs in the subsurface environment is termed "Vapor Intrusion." This document contains limited Pilot Program Guidance (PPG) on how to evaluate the potential for vapor intrusion at residential, commercial and industrial sites.

Residential sites include homes, apartments, and other dwellings, and are evaluated using exposure calculations beginning with a child only exposure scenario for shorter exposure durations, and continuing through age-adjusted exposure scenarios as the exposure duration increases. All risk is calculated at the 1.0 x 10^{-5} risk level using standard U. S. Environmental Protection Agency (EPA) inputs for body weight, exposure frequency and inhalation. Commercial sites include typical workplaces such as offices and other businesses where exposure to vapor-phase contaminants would not be expected based on normal operations, and which are not regulated by the Occupational Safety and Health Administration (OSHA). Commercial sites are evaluated using an adult-only exposure scenario. Residential and commercial indoor air action levels and ground water, soil gas, and sub-slab vapor screening levels are presented in the tables that appear in Appendix VIII. Industrial sites include manufacturing facilities and other workplaces where exposure to vapor-phase contaminants could be expected based on normal operations, and which are regulated by OSHA. Indoor air action levels and ground water and soil gas screening levels for industrial sites are presented in Appendix V. Indoor air is generally understood to mean the breathable air inside any habitable or workplace structure

This Pilot Program Guidance is intended to provide interim guidance at sites while site-specific data are collected in order to develop an official Non-Rule Policy. Because IDEM is aware of the economic impact from unnecessary investigation, empirical data will be collected to verify and/or adjust screening parameters. The PPG does not present requirements for site investigation. At this time, IDEM does not have official guidance, nor does the PPG present IDEM's Vapor Intrusion investigation policy. Instead, it defines a Pilot Program that will be used to develop this policy.

Soil and groundwater screening levels presented in this guidance document may change. They are based on theoretical models that may be conservative. In the absence of sufficient empirical data, the PPG screening levels represent IDEM's best effort to define health-protective concentrations below which further evaluation is not necessary. Over time, site-specific vapor data will be collected and evaluated to determine if the screening level models should be changed. The empirical data collected will either provide support for changing the current screening levels, or support the use of current levels. Either outcome will result in the development of NPD guidance that can be definitively used for vapor investigations at a given site.

The investigator should remember, for vapor intrusion, it is only indoor air samples that are considered definitive and are used to determine the need for corrective action. Screening parameters may indicate the likelihood of a vapor intrusion problem. A site may be screened out, but will not move to corrective action unless the vapor intrusion pathway is determined to be complete, and indoor air samples confirm that vapor intrusion is occurring at concentrations above health protective levels.

The IDEM site manager and the responsible party or their consultant have the opportunity to use the PPG approach presented here, but it is not required. Responsibilities for site investigation remain with the responsible party or their consultant, and oversight of the site investigation remains with the IDEM Project Manager. If the responsible party chooses not to follow the Pilot Program, they should present IDEM with a clear, detailed, and scientifically defensible Work Plan indicating how they intend to proceed.

The IDEM vapor intrusion guidance is intended to provide a rational, sequential method to determine if the vapor exposure pathway is complete, from a source area (contaminated soil or ground water), through soil gas in the unsaturated zone, to a potential receptor in an occupied building. The PPG addresses two major categories of affected sites: gasoline releases, such as those from underground storage tanks (USTs), and chlorinated solvent releases, such as those from dry cleaners or old industrial sites. In this guidance, gasoline release sites are termed "BTEX sites", and chlorinated solvent release sites are termed "Chlorinated sites". Volatile petroleum hydrocarbons have significantly different physical and chemical properties than chlorinated solvents. In addition, BTEX constituents generally biodegrade aerobically in the subsurface whereas chlorinated constituents generally do not. Because of the differences in properties, vapor intrusion investigations differ somewhat depending on the contaminants of concern. Therefore, this guidance is presented in two parts; Part A addresses BTEX sites, and Part B addresses Chlorinated sites.

A pilot program for commercial or industrial sites has also been developed. For sites where there is a potential for vapor intrusion into a commercial or industrial building, investigators should follow this guidance and also review the information presented in Appendix V. Potentially affected sites with sensitive populations, such as schools or day care centers should be evaluated using residential exposure criteria and should be preferentially selected for sampling if screening indicates that soil gas or indoor air sampling is necessary.

Sites with the potential for vapor intrusion are among the most complicated to characterize. A number of significant problems affect measurement and interpretation of results, for instance:

- The measurement of volatile organic contaminants (VOCs) in indoor air is often confounded by identical VOCs commonly used in household products, such as cleaners, detergents, solvents, or fuels;

- Changing atmospheric conditions such as wind, barometric pressure and precipitation may rapidly affect indoor air VOC concentrations;

- Shallow ground water increases vapor intrusion potential more than deep ground water, and;

- When assessing the full impact from VOCs, consideration must be given to the potential for biodegradation, which occurs readily at BTEX sites but has little impact at Chlorinated sites.

Despite these problems, a great deal of progress has been made in assessing the vapor intrusion pathway. Assessing the health impacts from this pathway is important since the health risks from breathing VOCs in air are much greater than from drinking comparably contaminated water. In addition, the potential for health related risks might go unnoticed, since health protective levels are often below odor or taste thresholds.

This guidance is not meant to be all encompassing, it is merely a procedure intended to help project managers and responsible parties or their consultants evaluate the potential for vapor intrusion at sites. Although this guidance may apply to a large percentage of sites, site conditions and applications vary widely, and expectations for universal guidance are unrealistic. Users should be cautious about noting conditions where this guidance may not be applicable.

DRAFT
Vapor Intrusion Pilot Program

Part A, BTEX Compounds

1.0 Overview

Preliminary screening evaluation:

- Evaluate the site and surrounding properties for potential receptors. Identify surrounding properties, and note the locations of residential properties and buildings with sensitive populations such as day care centers and schools. Identify which structures have basements, crawlspaces, or slab-on-grade construction.

- Determine if the concentrations of benzene in ground water exceed screening levels within 50 feet of an occupied building. Contaminated ground water greater than 50 feet from an occupied building is not expected to pose a threat unless preferential pathways are present connecting the contaminated ground water and the building. Ground water screening levels for benzene are presented in Appendix VIII, Table 1, and are discussed in Section 3.1 of this guidance document.

- Determine if the concentrations of benzene in soil exceed the screening level within 50 feet of an occupied building. Contaminated soils greater than 50 feet from an occupied building are not expected to pose a threat unless preferential pathways are present. Soil screening is presented in Section 3.2 of this guidance document.

- Evaluate potentially affected buildings for vulnerable characteristics, such as preferential pathways, earthen-floored basements, unlined crawlspaces, open sump pits or shallow ground water (less than 5 feet below the basement, crawlspace, or slab).

- If a preferential pathway exists, investigate it to determine if the potential for vapor intrusion into indoor air is significant.

If benzene concentrations exceed screening levels in ground water or soil within 50 feet of an occupied building then an investigation into contaminant concentrations in soil gas is warranted. For most sites, IDEM recommends a sequential approach that establishes the pathway from the source to a potential receptor by evaluating soil gas or sub-slab vapor samples prior to sampling indoor air. However, if soil or ground water concentrations are greater than 10 times the screening levels, or free-phase product is present or suspected, IDEM recommends prompt collection of paired sub-slab and indoor air samples. This allows for a more rapid assessment of potential exposure. Free-phase product may be suspected if a soil sample contains a contaminant at a concentration that exceeds the soil saturation concentration listed in Appendix 1, Table A of the *RISC Technical Resource Guidance Document* (IDEM, 2001).

Soil gas contamination can be evaluated in one of the following ways:

- Collect sub-slab vapor samples through the concrete slab of the building (basement or otherwise). For sub-slab sampling procedures see Appendix I and Section 4.0. Compare the results with the screening levels presented in Appendix VIII, Table 1 for sub-slab samples.

- Collect crawl space vapor samples if the building has a crawl space, (see Section 6.0). Compare the results with the screening levels presented in Appendix VIII, Table 1 for crawl space samples.

- If sub-slab or crawl space samples are not possible due to access or other restrictions, then collect soil vapor samples from outside the structure (see Appendix II and Section 5.0). Compare the results with the screening levels presented in Appendix VIII, Table 1 for soil gas samples.

If benzene concentrations in soil gas samples exceed screening levels, or soil or ground water concentrations are greater than 10 times the screening levels, then indoor air sampling is warranted. Determine if prompt action is required.

- Collect indoor air samples (See Appendix III and Section 7.0).

- Compare the results to the sub-chronic (short-term) indoor air action levels in Appendix VIII, Table 2 (residential sites) or Table 3 (commercial sites) and take prompt action to reduce exposure to building occupants when these levels are exceeded.

- Compare results to the chronic indoor air action levels in Appendix VIII, Table 2 (residential sites) or Table 3 (commercial sites) and determine if long term monitoring or further evaluation is necessary through additional indoor air sampling.

2.0 Introduction to Vapor Intrusion at BTEX Sites

Benzene, as a carcinogen, is the predominant contaminant of concern at BTEX sites. Although Methyl Tertiary Butyl Ether (MTBE) is a suspected carcinogen, and is often present at BTEX sites, the indoor air health protective levels are considerably higher than benzene. The same is true for the noncarcinogens: toluene, ethylbenzene and xylene, and the noncarcinogenic toxic effects of benzene. The health protective levels of these noncarcinogens are much greater than the carcinogenic health protective level for benzene. Benzene, as a carcinogen, presents a human-health risk based on exposure duration. The longer the exposure to benzene the greater the health risk to any exposed individuals.

Because benzene biodegrades in ground water, consideration is given to the length of time it takes benzene concentrations in a ground water plume to increase to a level that might create an indoor air health problem, how long it will maintain that level of exposure, and then the length of time it takes to decrease concentrations below levels of concern. As a default, it is assumed that the ground water plume moves through this cycle over the course of approximately five years. Accordingly, if it is expected that benzene levels in the ground water will remain above screening levels for longer than five years, then a non-default approach to development of alternative screening levels will have to be taken. IDEM RISC personnel should be consulted if alternative exposure duration evaluations are necessary at a BTEX site. Ground water screening levels for benzene (residential and commercial) are presented by soil type and depth to ground water in Appendix VIII, Table 1. Screening levels for soil investigations are presented in Section 3.2.

3.0 Preliminary Screening Evaluation

Preliminary screening is undertaken to determine if contaminant concentrations in the ground water or soil are above action levels, if preferential pathways exist, and if potential receptors are present. There should be sufficient information available to make these initial determinations in the form of soil and ground water sampling data and other site related information. Some things to be considered are:

- What contaminants are found at the site, and is benzene present?

- Are there occupied buildings (or will there be within the next five years) overlying or within 50 feet of areas where the plume is above screening levels?

- Do immediate threats, such as fire/explosion, exist? If yes, then the investigator should address these threats first (this guidance does not address fire and explosion issues).

- Are there noticeable petroleum odors or complaints of petroleum odors? If these conditions exist in the absence of obvious indoor sources for the odors, then the exposure pathway is assumed to be complete, and indoor air should be sampled promptly (see Section 7.0).

- Is contaminated ground water present within five feet of the basement, slab or ground surface? If so this guidance does not apply, and indoor air should be sampled promptly (see Section 7.0).

- Do preferential pathways exist that may connect source areas to indoor air, (*e.g.* sewer lines, utility conduits, sand lenses)? If yes, then these preferential pathways should be investigated to determine if indoor air sampling is warranted.

- What soil types are present? Ground water screening levels presented in Appendix VIII, Table 1 vary by soil type. In the absence of laboratory analyses of soils, use the ground water screening values for Sand or Sand and Gravel that appear in Appendix VIII, Table 1 as the default. If another soil type is present, laboratory grain-size analytical data should be submitted confirming the site-specific soil classification.

- Is it likely that the concentration of benzene in ground water will not be reduced to less than screening levels either by remedial actions or natural attenuation within the next five years? If so, non-default screening levels should be calculated based on a longer exposure period.

3.1 Ground Water Contamination Screening

Ground water screening levels appear in Appendix VIII, Table 1. Ground water screening levels are determined based on depth to ground water, and soil type. The higher screening levels presented in Appendix VIII, Table 1 may be allowed if it can be demonstrated that less permeable soils or deeper ground water are present at a site.

The default soil type for ground water screening is sand or sand and gravel. Because of the sensitivity of soil type on ground water screening levels, soil types other than sand or sand and gravel should be confirmed by laboratory analyses of grain size distribution on a number of samples collected from the unsaturated zone.

Depth to ground water is based on the highest (shallowest) seasonal ground water level, and site-specific ground water levels that fall between the depths listed in Appendix VIII, Table 1 are rounded to the next shallowest depth (e.g. the screening level for a measured depth to ground water level of 8.6 feet would be found in the 5 ft. depth column of Appendix VIII, Table 1).

If a site exceeds ground water or soil screening levels, then sub-slab or soil gas sampling is advised. If contaminant levels in ground water are greater than ten times the screening levels, then prompt, simultaneous evaluation of both sub-slab gas and indoor air is recommended. This allows for a more rapid evaluation of potential exposure concentrations in indoor air.

3.2 Soil Contamination Screening

At this time there does not appear to be a process to derive soil screening levels that is widely accepted by the scientific and professional community. IDEM is attempting to determine soil screening levels using site-specific data. In the interim, IDEM is suggesting the use of 10 mg/kg benzene in the soil as a screening level. If concentrations of benzene in the soil are greater than 10 mg/kg and within 50 feet of an occupied building then sub-slab or soil gas sampling is warranted. The preferred method is sub-slab or crawl space sampling. If that is not possible, then soil gas sampling may be used, but it is not as definitive as a sub-slab or crawl space sample. Sub-slab sampling procedures are discussed in Appendix I, and soil gas sampling procedures are discussed in Appendix II. Alternatives to the use of the IDEM default soil screening levels may be proposed if it can be adequately demonstrated using site-specific conditions that the alternative soil screening levels are protective of human health, and will not allow vapor intrusion into nearby structures above health protective levels.

4.0 Sub-slab Sampling

Sub-slab sampling is generally the second screening step in evaluating BTEX sites for vapor intrusion. If an occupied building is located within 50 feet of a ground water plume exceeding screening levels, or there is soil contamination above 10 mg/kg within 50 feet of an occupied building, then sub-slab sampling is recommended. If contaminant concentrations in soil or ground water are greater than 10 times the screening level or free-phase product is suspected, IDEM recommends prompt collection of paired sub-slab and indoor air samples.

Sub-slab samples are soil vapor samples taken directly under the basement or slab and collected into an evacuated polished stainless steel canister (a Summa canister). Sub-slab sampling measures the potential for vapor intrusion, but is not definitive evidence that soil gas is entering the building. Only indoor air samples, that take into consideration the potential contribution from sources occurring within the building, provide clear and definitive evidence that contaminant vapors are entering the building.

The sub-slab vapor sampling procedures are presented in Appendix I. Once the sub-slab sample concentration has been determined, it is multiplied by a conservative attenuation factor to predict what the indoor air concentration may be. IDEM has chosen an attenuation factor of 0.1 (a 10X attenuation of the soil gas into the indoor air), based upon the recommendations of the EPA (2002). If sub-slab benzene concentrations exceed the screening level listed in Appendix VIII, Table 1, then indoor air sampling should be conducted. Alternatives to the use of the default screening levels may be proposed if it can be adequately demonstrated using site-specific conditions that the alternative screening levels are protective of human health, and will not allow vapor intrusion into nearby structures above health protective levels. Benzene concentrations within the Potential Chronic range listed in Appendix VIII, Table 1 may indicate a chronic (or long-term) vapor intrusion problem. In this case, further investigation, such as additional indoor air sampling over time, may be necessary.

The sub-slab action level presented in Appendix VIII, Table 1 is based on benzene, because the health protective concentrations for benzene are significantly lower than for other BTEX constituents. However, the results of a more comprehensive or broader VOC scan should be reported to determine if other potentially harmful constituents are present. The broader VOC scan analysis list may vary according to the specific goals of the sampling project, the analytical methodology and the laboratory performing the analysis. If the sub-slab VOC scan identifies any contaminants listed in Appendix VIII, Table 2, the sub-slab screening levels for these contaminants can be determined by multiplying the values in Appendix VIII, Table 2 (residential sites) or Appendix VIII, Table 3 (commercial sites) by 10. Any contaminant exceeding the sub-slab screening level requires further investigation and indoor air sampling is recommended.

If sub-slab sampling is performed, concentrations of oxygen, carbon dioxide, and methane should also be determined and reported to evaluate potential biodegradation of petroleum hydrocarbons in the subsurface.

5.0 Soil Gas Sampling

When it is not possible to obtain sub-slab or crawl space samples, then soil gas samples from soil gas monitoring points are necessary. The appropriate monitoring point construction and sampling methods are described in Appendix II (Draft Soil Gas Sampling Procedures). The samples should be collected from at least two depths, and at points located on two sides of the potentially affected building. If contaminated ground water is the potential source, soil gas samples should be collected on the assumed up-gradient and down-gradient sides of the building. If soil contamination is the potential source, soil gas samples should be collected from the side of the building closest to the source, and an additional soil gas sample should be collected from the opposite side of the building. One soil gas sample should be collected from a depth no less than five feet below the ground surface (bgs), in the case of slab-on-grade construction, or five feet below the basement floor. Samples collected from shallower depths may encounter significant problems with entraining surface air into the sample (as well as other effects) and are discouraged. The second sample should be collected several feet above the water table. Soil gas samples collected from multiple depths may not be averaged, nor may up-gradient and down-gradient samples collected around a building be averaged. All soil gas samples should be individually compared to the appropriate screening levels in Appendix VIII, Table 1.

The appropriate attenuation factor for shallow soil gas samples is 0.01. If a soil gas vapor concentration is greater than the Prompt Action level presented in Appendix VIII, Table 1, then indoor air should be sampled. Alternatives to the use of the default screening levels may be proposed if it can be adequately demonstrated using site-specific conditions that the alternative screening levels are protective of human health, and will not allow vapor intrusion into nearby structures above health protective levels. If soil gas concentrations are within the Potential Chronic range in Appendix VIII, Table 1, a chronic vapor intrusion problem may exist and further investigation may be necessary to assess potential risk.

The soil gas action level presented in Appendix VIII, Table 1 is based on benzene, because the health protective concentrations for benzene are significantly lower than for other BTEX constituents. However, the results of a more comprehensive or broader VOC scan should be reported to determine if other potentially harmful constituents are present. The broader VOC scan analysis list may vary according to the specific goals of the sampling project, the analytical methodology and the laboratory performing the analysis. If the soil gas VOC scan identifies any contaminants listed in Appendix VIII, Table 2, the soil gas screening levels for these contaminants can be determined by multiplying the values in Appendix VIII, Table 2 (residential sites) or Appendix VIII, Table 3 (commercial sites) by 100. Any contaminant exceeding the screening level will require further investigation and indoor air sampling is recommended.

If soil gas sampling is performed, concentrations of oxygen, carbon dioxide, and methane should also be determined and reported to evaluate potential biodegradation of petroleum hydrocarbons in the subsurface.

6.0 Crawl Space Sampling

If the house has a crawl space, then an air sample should be collected there, and no attenuation into the indoor air is assumed, (*i.e.* the attenuation factor is 1.0). The crawl space sample should be collected using the same procedures used for an indoor air sample (see Section 7.0, and Appendix III). Samples should be taken from the center and away from the sides of the crawl space. Benzene concentrations from an air sample collected in a crawl space are compared to the crawl space values presented in Appendix VIII, Table 1. If benzene concentrations exceed the Prompt Action level in Appendix VIII, Table 1, then action should be taken to continue the investigation (by additional indoor air sampling) or to reduce exposure. Benzene concentrations within the range listed in the Potential Chronic column of Appendix VIII, Table 1 may indicate a chronic (or long-term) vapor intrusion problem. In this case, further investigation, such as additional indoor air sampling over time, may be necessary.

The crawl space action level presented in Appendix VIII, Table 1 is based on benzene, because the health protective concentrations for benzene are significantly lower than for other BTEX constituents. However, the results of a more comprehensive or broader VOC scan should be reported to determine if other potentially harmful constituents are present. The broader VOC scan analysis list may vary according to the specific goals of the sampling project, the analytical methodology and the laboratory performing the analysis. If the VOC scan identifies any contaminants listed in Appendix VIII, Table 2, the concentrations of these contaminants should be compared to the indoor air values presented in Appendix VIII, Table 2 (residential sites) or Appendix VIII, Table 3 (commercial sites).

Determination of oxygen, carbon dioxide, and methane concentrations is not necessary for crawl space samples.

7.0 Indoor Air Sampling

If a site fails sub-slab or soil gas screening, if contaminant concentrations in soil or ground water exceed screening levels by a factor of 10, or if free-phase product is suspected, then further investigation is required and prompt indoor air sampling is recommended.. The interpretation of indoor air sample results may be complicated by the presence of atmospheric and indoor sources of the same contaminants which are being evaluated for vapor intrusion. Indoor air sources of some contaminants are commonly found in the home and may originate from activities such as cigarette smoking and from everyday household products such as cleaning supplies and stored fuels. These sources of indoor air contaminants are called indoor air background, and may exceed IDEM's long-term (chronic) action levels, but generally will not exceed shorter-term action levels.

When collecting indoor air samples, the samples should be obtained during a period that maximizes the potential for vapor intrusion, (*i.e.* a “worst case” scenario). While worst case conditions typically occur during the late winter or early spring, the investigator should not wait if the need for sampling occurs outside those seasons. However, if indoor air sampling does not occur during worst case conditions, an additional set of indoor air samples collected under worst case conditions may be necessary to confirm the initial results.

If samples collected under worst-case conditions do not exceed action levels, then it can be assumed that unsafe conditions will not occur unless contaminant concentrations in the source area(s) increase. Some conditions that should maximize vapor intrusion include:

- A closed-up building (no open windows, minimized traffic in and out of the house). It is best if the structure can be closed up for at least 24 hours prior to sampling.
- The mechanical heating/cooling system is operating.
- The indoor air temperature is at least 10º F greater than the outdoor temperature.
- Late winter/early spring (frozen soil) or soil saturated with water.

Before any indoor air sampling is started, a detailed survey of the building and the activities of the occupants should be conducted. Special attention should be paid to the presence of common household items or chemicals, such as cleaning supplies, and fuels that may be sources of indoor air contaminant concentrations that exceed health protective levels. Indoor air sampling is discussed briefly in Appendix III, and an example indoor air building survey checklist is provided in Appendix IV.

Sampling locations within a building should be chosen with the following criteria in mind:

- At least two samples should be collected inside the building, and at least one sample should be collected on each floor of a multi-story building.
- The commonly occupied areas of the building should be sampled, as well as the basement (if present). Samples should not be collected from generally unoccupied spaces such as closets or storage areas.
- Samples should be collected in the area expected to have the highest vapor concentrations such as ground floors and basements.
- Samples should be drawn from the breathing zone (3 – 5 feet above the ground, lower if small children are present).
- Samples should be taken from areas with good air circulation, such as the center of the room.
- The sampling period should be approximately 24 hours.

At least one outdoor ambient air sample should be taken simultaneously with the indoor air samples. The following criteria should be considered.

- The ambient air sample should be collected at least 15 feet upwind from the building.

- The intake should be approximately five feet above the ground.
- Ambient samples should not be collected in proximity to obvious potential sources such as parked vehicles or fuel tanks.
- The ambient air sampling should begin one to two hours before the indoor air sampling begins.

If indoor air values are greater than the Sub-Chronic Action levels presented in Appendix VIII, Table 2 (residential sites) or Table 3 (commercial sites), then action should be taken to reduce exposure. Prompt action does not necessarily mean evacuating the premises. It can often take the form of installation of a venting system or any other means that will reduce exposure to an acceptable level. If concentrations in the indoor air are within the range of values based on exposure duration listed in the chronic columns of Appendix VIII, Table 2 (residential sites) or Table 3 (commercial sites), then a chronic vapor intrusion problem may exist. Further investigation or additional sampling will be necessary to assess potential risk.

8.0 Evaluation of Chronic Exposure Conditions

If indoor air levels are within the chronic range of values based on exposure duration listed in Appendix VIII, Table 2 (residential sites) or Table 3 (commercial sites), or soil gas samples, crawl space samples, or sub-slab samples are within the Potential chronic ranges listed in Appendix VIII, Table 1, then a chronic (or long-term) exposure problem may be indicated. Chronic problems can occur from vapor intruding at low levels over long periods of time. It may be necessary to further characterize the exposure. Often, levels of benzene within the Potential Chronic range are not the result of vapor intruding at low levels, but instead are the result of improper gasoline storage, hobbies or other common indoor air background sources. Evaluation of the indoor air data in conjunction with soil gas or sub-slab soil vapor data may indicate whether contaminants detected in indoor air are the result of vapor intrusion, or result from background sources within the building.

9.0 Corrective Action

If the vapor intrusion pathway is determined to be complete, and contaminant concentrations in indoor air exceed the Sub-Chronic Action levels [Appendix VIII, Table 2 (residential sites) or Table 3 (commercial sites)], then active vapor mitigation will be necessary. If contaminant concentrations are within the chronic range of values based on exposure duration, then IDEM will evaluate the need for active remediation on a site-specific basis. This evaluation will be based on the contaminant concentrations, the estimated time of exposure prior to discovery, and the estimated time that will be required before contaminant concentrations decrease to acceptable levels.

The most common method of controlling vapor intrusion is to block the migration pathway at the point where vapors enter a building by installing a vapor mitigation system, sometimes called a “Radon System”. The most common type of vapor mitigation system, called a sub-slab depressurization system or a sub-slab ventilation system, has been used for many years to prevent radon from infiltrating from soils into buildings, and is also effective for preventing contaminant vapors from entering buildings. The U. S. Environmental Protection Agency (EPA) has developed a number of publications that describe the proper design, installation, and operation of sub-slab depressurization systems. For information on sub-slab depressurization systems IDEM recommends the following EPA publications;

EPA (2003) *Consumer Guide to Radon Reduction*:
Available at: http://www.epa.gov/radon/pubs/consguid.html

EPA (1994) *Radon Mitigation Standards*
Available at: http://www.epa.gov/radon/pubs/mitstds.html

Methods to reduce or prevent vapor intrusion are more effective and easier to install if incorporated into the design of buildings under construction. The following EPA publications and websites are recommended for sites where new building construction is anticipated, and vapor intrusion may be an issue;

The EPA *Radon-Resistant New Construction* webpage (http://www.epa.gov/radon/construc.html)

EPA (2001) *Building Radon Out*
Available at: http://www.epa.gov/radon/construc.html

Other techniques which help to reduce vapor intrusion into buildings include sealing cracks or openings in foundation walls or slabs, sealing open sump pits, and installation of vapor barriers in crawl spaces or over earthen basement floors. These techniques are often performed in conjunction with installation of a sub-slab depressurization system.

Contractors who install radon mitigation systems in residential buildings in Indiana must be certified by the Indiana State Department of Health (ISDH). IDEM recommends that installation of sub-slab depressurization systems for vapor intrusion sites be performed by an ISDH certified contractor. A list of certified contractors can be found at:

http://www.in.gov/isdh/regsvcs/radhealth/radon.htm

A properly installed sub-slab depressurization system does not reduce contaminant concentrations in the source area, but does effectively prevent contaminant vapors from entering occupied structures. IDEM expects that active remediation of the contaminant source area will also be conducted at any site where a sub-slab depressurization system, or other remedial measures, are needed to protect receptors. Because remediation of a contaminant source area may take years to complete, any exposure prevention measures taken, such as installation of sub-slab depressurization system, will require periodic inspection and maintenance to ensure that the systems are operating safely and effectively, and that potential receptors are protected. Inspection of the systems on a quarterly basis is recommended, and the systems should be maintained until the source areas are fully remediated and closed.

Additional information on remedial action for vapor intrusion site can be found in State of New Jersey (2005), and State of California (2005).

10.0 BTEX Compounds Technical Basis and Rationale

The pilot program described in this document has two major goals. The first is to provide a default approach to site investigations at potential vapor intrusion sites, and the second is to determine screening levels in the subsurface that are both health protective and reasonable. Indoor air health protective levels can be defined following the risk-based approach outlined by the IDEM RISC program (IDEM, 2001). Reasonable must be defined as health protective, but not so conservatively health protective that the false positive investigation rate becomes economically burdensome to responsible parties. IDEM has attempted to initially define screening levels that minimize the false positive rate and meet the health protective guidelines provided in the *RISC Technical Resource Guidance Document* (IDEM, 2001). While the pilot program provides a starting point, ultimately the determination of both health protective and reasonable screening levels will require the use of empirical data. The data from site-specific investigations will be collected and analyzed over time. The analyses will allow IDEM to adjust and refine screening levels in the subsurface that are consistent with the goal of "health protective and reasonable."

Default vapor intrusion approaches that are health protective and reasonable are difficult to develop due to a number of issues, including: predicting concentrations in oxygenated environments, indoor air background levels that exceed chronic health protective levels, reliable soil gas measurement processes, and reasonable subslab and soil gas attenuation factors. Developing default screening levels requires an understanding of how these issues complicate default site investigations. For instance, it is difficult to determine if a chronic indoor air problem is caused by vapor intrusion when indoor air measurements frequently exceed chronic health protective levels due to indoor air background levels caused by lifestyle choices. Additionally, it is difficult to determine screening levels for degradable constituents such as BTEX compounds when defining guidance (EPA, 2002) does not account for biodegradation of potential contaminants.

The development of screening levels recognizes that biodegradation occurs for BTEX compounds in most subsurface environments. If it becomes necessary to investigate the soil environment or sample inside the home, then IDEM has separated corrective action decisions into two groups, those requiring prompt action, and those requiring further investigation to determine if corrective action is warranted. These approaches are consistent with the goals of being health protective and reasonable in a default site investigation process.

10.1 General Program Description

The pilot program approach recommends a sequential site investigation process, beginning with soil and/or ground water screening. If soil or ground water concentrations exceed screening levels, then soil gas or sub-slab vapor samples are collected and compared to screening levels. If soil gas or sub-slab vapor samples exceed screening levels, then indoor air sampling is necessary. Indoor air samples are the only definitive sample that can be used to require corrective action for the vapor intrusion pathway. Assuming the site meets certain qualifying conditions, then the site may be screened out if soil and ground water concentrations are below their screening levels, or if the soil gas or sub-slab results are below their screening values.

The screening levels for BTEX sites were developed using benzene as the screening compound. As a carcinogen, benzene is the primary constituent of concern at BTEX sites, with health protective concentrations significantly lower than any other BTEX constituent, including MTBE.

A significant problem in development of the default site approach is determining realistic health protective screening levels for BTEX that account for attenuation known to occur in oxygenated subsurface environments. IDEM has attempted to account for subsurface biodegradation of BTEX vapors to some extent by reducing the area of potential investigations. The maximum distance from a source area to a potential receptor was reduced from 100 feet, as recommended by the EPA (2002), to 50 feet for BTEX constituents. However, consistent with EPA (2002) guidance, attenuation factors were not adjusted for BTEX constituents to account for potential biodegradation.

10.2 Soil Screening Levels

A screening level for benzene in soils was developed using the Johnson & Ettinger Model (Version 3.0) available from the EPA. IDEM used a one-year exposure duration (ED) and approximated sources 25 to 100 ft. from a residence, across several soil types with varying organic carbon content from 0.002 to 0.004. A soil screening level of 10 mg/kg was derived from the model testing. This screening level may be adjusted as site-specific data are collected and evaluated.

The screening level for benzene in soils is significantly greater than the RISC default industrial closure level. Therefore, at this concentration, sites will generally need to undertake source removal or remediation of soils regardless of whether the vapor intrusion pathway is present. However, it is expected that at most sites, ground water concentrations will be used to determine if it is necessary to perform soil gas investigations.

10.3 Ground Water Screening Levels

Screening levels in ground water were developed recognizing that biodegradation generally occurs in both the ground water, and the unsaturated (vadose) zone soils. An attenuating plume reduces the period of time over which an individual may be exposed to contaminant vapors. For carcinogens, acceptable indoor air concentrations are based on a 1×10^{-5} risk level. Therefore, acceptable indoor air concentrations are greater for a short exposure duration than for longer-term exposure. Determining health protective levels for ground water screening values requires an estimate of the amount of time over which exposure is expected to occur, and the average concentration as the plume degrades to lower levels.

IDEM has estimated that generally, a BTEX plume at a typical LUST site degrades to low levels within about five years, assuming the contaminant source is controlled. A representative exposure level across this time period was then assumed to be commensurate with that of a three year exposure duration. Selection of this exposure duration attempts to account for the period of time required for a plume to travel to a receptor, as concentrations are increasing, and the corresponding decrease in concentrations over time as the plume degrades. It also assumes source removal will occur over this period of time. A non-default approach will have to be used if the exposure duration has exceeded five years, or where it is suspected that ground water concentrations will not degrade to low levels in five years. In this case, lower screening levels will be calculated based on the longer exposure duration.

The default health protective levels for residential properties were calculated using child only or age-adjusted exposure assumptions at the 1×10^{-5} risk level. For commercial properties, the default exposure duration was used with adult only exposure assumptions, at the 1×10^{-5} risk level, to calculate health protective indoor air action levels.

Once acceptable indoor air action levels were derived, ground water screening levels were back-calculated using the attenuation equation presented in Appendix F of the EPA (2002) guidance document.

$$C_{gw} = \frac{C_{indoor}}{\alpha \ x \ H_c}$$

Where:

C_{gw} = Concentration in ground water (ug/l) x 1000 L/m^3
C_{indoor} = Acceptable indoor air concentration
H_c = Henry's Law Constant corrected for ground water temperature
α = Attenuation factor derived from Figure 3b of EPA (2002), varying by depth to ground water and soil type

A significant factor in determining reasonable ground water screening levels is the use of a Henry's Law Constant corrected for subsurface temperatures, rather than the widely reported values determined for a temperature of about 25^o C. Correction of Henry's Law for lower temperatures in the subsurface produces higher, although reliable, ground water screening levels.

10.4 Soil gas/Sub-slab Screening Levels

If soil or ground water screening levels are exceeded, then soil gas or sub-slab sampling is recommended. Subslab sampling procedures recommended by IDEM are presented in DiGiulio (1, 2) and EPA (2006). Where sub-slab sampling is not possible or desired, soil gas sampling is recommended. Recommended soil gas sampling procedures are based on the information provided in API (2004), Hartman (2004) and State of California (2003), and are included in Appendix II.

Soil gas and sub-slab attenuation factors of 0.01 and 0.1, respectively, were based on EPA (2002) guidance. These attenuation factors are empirically derived.

Sub-slab and soil gas screening levels are derived from indoor air levels, multiplied by the appropriate attenuation factor. Two sets of screening levels were derived; Prompt Action levels, and Potential Chronic levels. Prompt Action levels were calculated using a one-year exposure duration, child only exposure. Potential Chronic screening levels are defined as a range from the one-year ED child only calculation, up to a 30 year, age-adjusted risk calculation. All risk is calculated at 1.0×10^{-5} using standard EPA inputs for body weight, exposure frequency and inhalation.

IDEM takes the position that risk greater than 1.0×10^{-5} requires prompt action. Soil gas or sub-slab gas concentrations exceeding the Prompt Action levels necessitate immediate action. Prompt sampling of indoor air is recommended. If the sub-slab or soil gas sample results fall within the Potential Chronic range, then further investigation is warranted, but indoor air sampling may or may not be indicated.

10.5 Indoor Air Action Levels

If indoor air sample results exceed the Sub-Chronic action levels presented in Appendix VIII, Table 2 (residential sites) or Table 3 (commercial sites), then immediate corrective action to reduce the exposure is required. This may occur by many different methods, including: prompt installation of a home ventilation or remediation system or other means of reducing exposure. If indoor air samples are within the chronic range of values based on exposure duration, then further investigation is warranted. Further investigation may include additional indoor air sampling over time or corrective action. The need for further investigation or corrective action will be decided on a case by case basis.

DRAFT
Vapor Intrusion Pilot Program

Part B, Chlorinated Compounds

1.0 Overview

Preliminary screening evaluation:

- Evaluate the site and surrounding properties for potential receptors. Identify surrounding properties, and note the locations of residential properties and buildings with sensitive populations such as day care centers and schools. Identify which structures have basements, crawlspaces, or slab-on-grade construction.

- Determine if ground water concentrations of chlorinated contaminants in ground water exceed screening levels within 100 feet of an occupied building. Contaminated ground water greater than 100 feet from an occupied building is not expected to pose a threat unless preferential pathways are present connecting the contaminated ground water and the building. Ground water screening levels for chlorinated compounds are presented in Appendix VIII, Table 4 (residential sites) and Table 5 (commercial sites), and are discussed in Section 3.1 of this guidance document.

- Determine if the concentrations of chlorinated contaminants in soil exceed screening levels within 100 feet of an occupied building. Contaminated soils greater than 100 feet from an occupied building are not expected to pose a threat unless preferential pathways are present. Soil screening levels for chlorinated compounds are presented in Appendix VIII, Table 6, and are discussed in Section 3.2 of this guidance document.

- Evaluate potentially affected buildings for vulnerable characteristics, such as preferential pathways, earthen-floored basements, unlined crawlspaces, open sump pits, or shallow ground water (less than 5 feet below the basement, crawlspace, or slab).

- If a preferential pathway exists, investigate it to determine if the potential for vapor intrusion into indoor air is significant.

If concentrations of chlorinated contaminants exceed screening levels in ground water or soil within 100 feet of an occupied building, then an investigation into contaminant concentrations in soil gas is warranted. For most sites, IDEM recommends a sequential approach that establishes the pathway from the source to a potential receptor by evaluating soil gas or sub-slab vapor samples prior to sampling indoor air. However, if soil or ground water concentrations are greater than 10 times the screening levels, or free-phase product (NAPL) is present or suspected, IDEM recommends prompt collection of paired sub-slab and indoor air samples. This allows for a more rapid assessment of potential exposure. Free product or NAPL may be suspected if a soil sample contains a contaminant at a concentration that exceeds the soil saturation concentration listed in Appendix 1, Table A of the *RISC Technical Resource Guidance Document* (IDEM, 2001).

Soil gas contamination can be evaluated in one of the following ways:

- o Collect sub-slab vapor samples through the concrete slab of the building (basement or otherwise). For sub-slab sampling procedures see Appendix I and Section 4.0. Compare the results with the screening levels presented in Appendix VIII, Table 7 (for residential sites) or Table 8 (for commercial sites) for sub-slab samples.

- o Collect crawl space vapor samples if the building has a crawl space (see Section 6.0). Compare the results with the screening levels presented in Appendix VIII, Table 7 (for residential sites) or Table 8 (for commercial sites) for crawl space samples.

- o If sub-slab or crawl space samples are not possible due to access or other restrictions then collect soil vapor samples from outside the structure (see Appendix II and Section 5.0). Compare the results with the screening levels presented in Appendix VIII, Table 7 (for residential sites) or Table 8 (for commercial sites) for soil gas samples.

If contaminant concentrations in soil gas samples exceed screening levels, or soil or ground water concentrations are greater than 10 times the screening levels, then indoor air sampling is warranted. Determine if prompt action is required.

- o Collect indoor air samples (See Appendix III and Section 7.0).

- o Compare results to the indoor air Sub-Chronic action levels presented in Appendix VIII, Table 2 (residential sites), or Table 3 (commercial sites), and take prompt action to reduce exposure to building occupants when these levels are exceeded.

- o Compare results to the indoor air Chronic action levels presented in Appendix VIII, Table 2 (residential sites), or Table 3 (commercial sites), and determine if long term monitoring or further evaluation is necessary through sub-slab, soil gas, or indoor air sampling.

2.0 Introduction to Vapor Intrusion at Chlorinated Sites

Chlorinated compounds are generally considered to be quite stable, and their breakdown takes considerable time in most subsurface environments. This changes the basic site evaluation approach from that of BTEX sites. The nature of the change requires the project manager or the site evaluation team to estimate the length of exposure. The length of exposure is critical because corrective action is almost always triggered at a given site by carcinogens, and the risk from carcinogenic exposure is dependent on the exposure duration. Screening levels or action levels are set based on the exposure duration for the carcinogens.

Because chlorinated compounds generally break down slowly in most subsurface environments, concentrations in ground water may remain stable until remediation takes place. For this reason, ground water, sub-slab and soil gas screening level tables, are given for exposure durations of 1, 5, 10, 20, and 30 years. The tables include the most commonly encountered volatile chlorinated carcinogen species: tetrachloroethylene (PCE); trichloroethylene (TCE); 1,2-dichloroethane (1,2-DCA); and vinyl chloride (VC).

The project manager should recognize that an exact determination of exposure duration is often not possible; this uncertainty is somewhat offset by the conservative nature of the screening levels. The project manager should also recognize that failing the screening levels simply means indoor air samples must be collected and, that marginally passing screening levels using a reasonable estimate of exposure duration are still conservative.

This guidance is intended to provide a consistent approach while site-specific information and data are being collected to verify that the screening levels provided in the guidance are appropriate. Certain parameters are given in the guidance, such as screening levels, which are derived from theoretical models. Over time data will be collected and evaluated to determine if the screening level models should be reevaluated or changed.

3.0 Preliminary Screening Evaluation

Preliminary screening is undertaken to determine if contaminant concentrations in the ground water or the soil are above action levels, if preferential pathways exit, and if potential receptors are present. There should be sufficient information available to make these initial determinations in the form of soil and ground water sampling data and other site related information. Some things to be considered are:

- What are the contaminants found at the site, and do they include TCE, PCE, 1,2-DCA, or VC?
- Are there occupied buildings (or will there be) overlying or within 100 feet of areas where the plume is above screening levels?
- Do immediate threats such as fire/explosion exist? If yes, then address these threats first (this guidance does not address fire and explosion issues).
- Are there noticeable non-petroleum or solvent odors or complaints of odors? If these conditions exist in the absence of obvious indoor sources for the odors, then the exposure pathway is assumed to be complete, and indoor air should be sampled promptly (see Section 7.0).
- Is contaminated ground water present within five feet of the basement, slab or ground surface? If so this guidance does not apply, and paired sub-slab and indoor air samples should be collected promptly.
- Do preferential pathways exist that may connect source areas to indoor air (*e.g.* sewer lines, utility conduits, sand lenses, *etc*.)? If yes, then investigate to determine if indoor air sampling is warranted.
- What soil types are present? Ground water screening levels presented in Appendix VIII, Table 4 (residential sites) and Table 5 (commercial sites) vary by soil type. In the absence of laboratory analyses of soils, use the ground water screening values for Sand or Sand and Gravel that appear in Appendix VIII, Tables 4 and 5 as the default. If another soil type is present, laboratory grain-size analytical data should be submitted confirming the site-specific soil classification.

Use of the following is recommended to help determine exposure duration:

- How old is the site?

- How long has the plume been at existing levels?
- Is it likely that the plume has been at current concentration levels for some time?
- Is it reasonable to conclude that the plume is expanding, or that COC concentrations will increase?
- How extensive is the soil contamination?
- When will source removal or mitigation be undertaken?

Ground water screening levels for chlorinated compounds are contained in Appendix VIII, Table 4 (residential sites) and Table 5 (commercial sites) for 1, 5, 10, 20 and 30 years exposure duration. If ground water contamination at a site exceeds the ground water screening levels based on exposure duration, or there is contamination present in the soil above the concentrations listed in Appendix VIII, Table 6, then sub-slab, crawl space or soil gas sampling is advised. If a site exceeds ground water or soil screening levels by greater than 10 times the screening level, then prompt collection of paired sub-slab and indoor air samples is advised.

3.1 Ground Water Contamination Screening

Ground water screening levels are contained in Appendix VIII, Table 4 (residential sites) and Table 5 (commercial sites). Ground water screening levels are determined based on depth to ground water, and soil type. Higher screening levels may be allowed if it can be demonstrated that less permeable soils or deeper ground water are present at a site. The default soil type for ground water screening is sand or sand and gravel. Because of the sensitivity of soil type on ground water screening levels, soil types other than sand or sand and gravel should be confirmed by laboratory analyses of grain size distribution on a number of samples collected from the unsaturated zone.

Depth to ground water is based on the highest (shallowest) seasonal ground water level, and site-specific ground water levels that fall between the depths listed in Appendix VIII, Tables 4 and 5 are rounded up to the next shallowest depth (e.g. the screening level for a measured depth to ground water level of 8.6 feet would be found in the 5 ft. depth column of Appendix VIII, Table 4).

If a site exceeds ground water or soil screening levels, or preferential pathways are thought to be significant, then sub-slab or soil gas sampling is advised. If contaminant levels in ground water are greater than ten times the screening levels, then prompt, simultaneous evaluation of both sub-slab gas and indoor air is recommended. This allows for a more rapid evaluation of potential exposure concentrations in indoor air.

3.2 Soil Contamination Screening

At this time there does not appear to be a process to derive soil screening levels that is widely accepted by the scientific and professional community. IDEM is attempting to determine soil screening levels using site-specific data. In the interim, IDEM is suggesting that if the soil concentrations are greater than those listed in Appendix VIII, Table 6, and are within 100 feet of an occupied building, then sub-slab, crawl space or soil gas sampling is warranted. The preferred method is sub-slab or crawl space sampling. If that is not possible, then soil gas sampling may be used, but it is not as definitive as sub-slab or crawl space sampling. Sub-slab sampling procedures are discussed in Appendix I, and soil gas sampling procedures are discussed in Appendix II. Alternatives to the use of the default soil screening levels may be proposed if it can be adequately demonstrated using site-specific conditions that the alternative soil screening levels are protective of human health, and will not allow vapor intrusion into nearby structures above health protective levels.

4.0 Sub-slab Sampling

Sub-slab sampling is generally the second step in evaluating chlorinated sites for vapor intrusion. If a site fails ground water screening (Appendix VIII, Tables 4 and 5), there is soil contamination above soil screening levels (Appendix VIII, Table 6), then sub-slab sampling is recommended. If contaminant concentrations in soil or ground water are greater than 10 times the screening level or NAPL is suspected, it may be preferable to collect sub-slab and indoor air samples simultaneously. Sub-slab samples are soil vapor samples collected from directly under the basement or slab, and are collected into an evacuated polished stainless steel canister (a Summa canister). Sub-slab sampling measures the potential for vapor intrusion, but is not definitive evidence that soil gas is entering the building. Only indoor air samples, which take into consideration the potential contribution from sources occurring within the building, provide clear and definitive evidence that contaminant vapors are entering the building. The sub-slab vapor sampling procedures are presented in Appendix I. Once the sub-slab sample concentration has been determined, it is multiplied by a conservative attenuation factor to predict what the indoor air concentration may be. IDEM has chosen an attenuation factor of 0.1 (a 10X attenuation of the soil gas into the indoor air), based upon the recommendations of the EPA (2002). If a sub-slab chlorinated contaminant concentration exceeds the Prompt Action level in Appendix VIII, Table 7 (for residential sites) or Table 8 (for commercial sites), then prompt action should be taken to sample the indoor air. If concentrations fall in the Potential Chronic range, then further investigation may be warranted. Alternatives to the use of the IDEM default attenuation factors or screening levels may be proposed if it can be adequately demonstrated using site-specific conditions that the alternative screening levels are protective of human health, and will not allow vapor intrusion into nearby structures above health protective levels.

The sub-slab action levels presented in Appendix VIII, Table 7 (residential sites) and Table 8 (commercial sites) are based on contaminants (1,2-DCA, PCE, TCE and VC) that IDEM expects to be most common at vapor intrusion sites, and for which health protective concentrations are relatively low. However, the results of a more comprehensive or broader VOC scan should be reported to determine if other potentially harmful constituents are present. The broader VOC scan analysis list may vary according to the specific goals of the sampling project, the analytical methodology and the laboratory performing the analysis. If the sub-slab VOC scan identifies any contaminants listed in Appendix VIII, Table 2, the sub-slab screening levels for these contaminants can be determined by multiplying the values in Appendix VIII, Table 2 (residential sites) or Appendix VIII, Table 3 (commercial sites) by 10. Any contaminant exceeding the sub-slab screening level will require further investigation and indoor air sampling is recommended.

5.0 Soil Gas Sampling

When it is not possible to obtain sub-slab or crawl space samples, then soil gas samples from soil gas monitoring points are necessary. The appropriate monitoring point construction and sampling methods are described in Appendix II. The samples should be collected from at least two depths, and at points located on the up-gradient and down-gradient sides of the potentially affected building. One sample should be collected from a depth no less than five feet below the ground surface (bgs), in the case of slab-on-grade construction, or five feet below the basement floor. Samples collected from shallower depths may encounter significant problems with entraining surface air into the sample (as well as other effects) and are discouraged. The second sample should be collected several feet above the water table.

Soil gas samples collected from multiple depths may not be averaged, nor may up-gradient and down-gradient samples collected around a building be averaged. All soil gas samples should be individually compared to the appropriate screening levels in Appendix VIII, Table 7 (for residential sites) or Table 8 (for commercial sites).

The appropriate attenuation factor for soil gas samples is 0.01. If a chlorinated contaminant concentration in soil gas exceeds the Prompt Action levels presented in Appendix VIII, Table 7 (for residential sites) or Table 8 (for commercial sites), then prompt action should be taken to sample the indoor air. If concentrations fall in the Potential Chronic range, then further investigation may be warranted. Alternatives to the use of the default attenuation factors may be proposed if it can be adequately demonstrated using site-specific conditions that the alternative screening levels are protective of human health, and will not allow vapor intrusion into nearby structures above health protective levels.

The soil gas action levels presented in Appendix VIII, Table 7 (residential sites) and Table 8 (commercial sites) are based on contaminants (1,2-DCA, PCE, TCE and VC) that IDEM expects to be most common at vapor intrusion sites, and for which health protective concentrations are relatively low. However, the results of a more comprehensive or broader VOC scan should be reported to determine if other potentially harmful constituents are present. The broader VOC scan analysis list may vary according to the specific goals of the sampling project, the analytical methodology and the laboratory performing the analysis. If the soil gas VOC scan identifies any contaminants listed in Appendix VIII, Table 2, the soil gas screening levels for these contaminants can be determined by multiplying the values in Appendix VIII, Table 2 (residential sites) or Appendix VIII, Table 3 (commercial sites) by 10. Any contaminant exceeding the soil gas screening level will require further investigation and indoor air sampling is recommended.

6.0 Crawl Space Sampling

If the house has a crawl space, then an air sample should be collected there. No attenuation into the indoor air is assumed, (*i.e.* the attenuation factor is 1.0). The crawl space sample should be collected using the same procedures used for an indoor air sample (see Section 7.0 and Appendix III). The sample probe or inlet should be close to the ground. Samples should be collected near the center and away from the sides of the crawl space. If contaminant concentrations exceed the Prompt Action levels presented in Appendix VIII, Table 7 (for residential sites) or Table 8 (for commercial sites), then prompt action should be taken to continue investigation or reduce the exposure within six months. If concentrations fall in the Potential Chronic range, then further investigation, such as additional air sampling over time, may be warranted.

The crawl space action levels presented in Appendix VIII, Table 7 (residential sites) and Table 8 (commercial sites) are based on contaminants (1,2-DCA, PCE, TCE and VC) that IDEM expects to be most common at vapor intrusion sites, and for which health protective concentrations are relatively low. However, the results of a more comprehensive or broader VOC scan should be reported to determine if other potentially harmful constituents are present. The broader VOC scan analysis list may vary according to the specific goals of the sampling project, the analytical methodology and the laboratory performing the analysis. If the VOC scan identifies any contaminants listed in Appendix VIII, Table 2, the concentrations of these contaminants should be compared to the indoor air values presented in Appendix VIII, Table 2 (residential sites) or Appendix VIII, Table 3 (commercial sites).

7.0 Indoor Air Sampling

If a site fails sub-slab or soil gas screening, if contaminant concentrations in soil and ground water exceed screening levels by a factor of 10, or if NAPL is suspected, then further investigation will be required and prompt indoor air sampling is recommended. Indoor air samples may be complicated by the presence of atmospheric and indoor sources of the same contaminants which are being evaluated for vapor intrusion. Indoor air sources of some contaminants are commonly found in the home and may originate from everyday household products such as cleaning supplies or stored fuels. These sources of indoor air contaminants are called indoor air background. These indoor sources may cause IDEM's Chronic (long-term) action levels to be exceeded, but generally will not cause Sub-Chronic (short-term) action levels to be exceeded.

When collecting indoor air samples, the samples should be taken during a period that maximizes the potential for vapor intrusion, (*i.e.* a "worst case" scenario). While worst case conditions typically occur during the late winter or early spring, the investigator should not wait if the need for sampling occurs outside those seasons. However, if indoor air sampling does not occur during worst case conditions, an additional set of indoor air samples collected under worst case conditions may be necessary to confirm the initial results.

There are other conditions that can maximize vapor migration (as listed below) and the investigator is encouraged to sample under those conditions. If samples collected under worst-case conditions do not exceed action levels, then it can be assumed that unsafe conditions will not occur unless contaminant concentrations in the source area(s) increase. Some conditions that would maximize vapor intrusion include:

- A closed-up building (no open windows, minimized traffic in and out of the house). It is best if the structure can be closed up for at least 24 hours prior to sampling.

- The mechanical heating/cooling system is operating.

- The indoor air temperature is at least 10º F greater than the outdoor temperature.

- Late winter/early spring (frozen soil) or soil saturated with water.

Before any indoor air sampling is done, a detailed survey of the building and the activities of the occupants should be conducted. Special attention should be paid to the presence of those common household items or chemicals, such as cleaning supplies, and fuels that may be sources of indoor air contaminant concentrations that exceed health protective levels. A more detailed explanation of indoor air sampling is included in Appendix III and an example building survey checklist is provided in Appendix IV.

Sampling locations within the home should be chosen with the following criteria in mind:

- At least two samples should be collected inside the building, and at least one sample should be collected on each floor of a multi-story building.

- The commonly occupied areas of the building should be sampled, as well as the basement (if present). Samples should not be collected from generally unoccupied spaces such as closets or storage areas.

- Samples should be collected in the areas expected to have the highest vapor concentrations, such as ground floors and basements.

- Samples should be drawn from the breathing zone (3 – 5 feet above the ground, lower if small children are present).

- Samples should be collected from areas with good air circulation, such as the center of the room.

- The sampling period should be approximately 24 hours.

At least one outdoor ambient air sample should be taken simultaneously with the indoor air samples. The following criteria should be considered.

- The ambient air sample should be collected at least 15 feet upwind from the building.

- The intake should be approximately five feet above the ground.

- Ambient samples should not be collected in proximity to obvious potential sources such as parked vehicles or fuel tanks.

- The ambient air sampling should begin one to two hours before the indoor air sampling begins.

If indoor air values are greater than the Sub-Chronic action levels listed in Appendix VIII, Table 2 (for residential sites) or Table 3 (for commercial sites), action should be taken to reduce exposure. Prompt action does not necessarily mean evacuating the premises. It can often take the form of installation of a venting system or any other means that will reduce exposure to an acceptable level.

8.0 Evaluation of Chronic Exposure Conditions

If indoor air levels are within the chronic range of values based on exposure duration listed in Appendix VIII, Table 2 (residential sites) or Table 3 (commercial sites), or soil gas samples, crawl space samples, or sub-slab samples are within the Potential Chronic ranges listed in Appendix VIII, Table 7 (residential sites) or Table 8 (commercial sites), it may indicate a chronic (or long-term) exposure problem. Chronic problems can occur from vapor intruding at low levels over long periods of times. It may be necessary to further characterize the exposure. Often levels of chlorinated contaminants above the chronic values are not the result of vapor intruding at low levels, but instead are the result of common household products, hobbies or other common indoor air background sources. If a chlorinated compound in an indoor air sample falls within the chronic range of values based on exposure duration listed in Appendix VIII, Table 2 (residential sites) or Table 3 (commercial sites) additional investigation may be required to determine if the contamination is caused by vapor intrusion or background sources. Evaluation of the indoor air data in conjunction with soil gas or sub-slab soil vapor data may indicate whether contaminants detected in indoor air are the result of vapor intrusion or result from background sources within the building.

9.0 Corrective Action

If the vapor intrusion pathway is determined to be complete, and contaminant concentrations in indoor air exceed the Sub-Chronic Action levels [Appendix VIII, Table 2 (residential sites) or Table 3 (commercial sites)], then active vapor mitigation will be necessary. If contaminant concentrations are within the chronic range of values based on exposure duration, then IDEM will evaluate the need for active remediation on a site-specific basis. This evaluation will be based on the contaminant concentrations, the estimated time of exposure prior to discovery, and the estimated time that will be required before contaminant concentrations decrease to acceptable levels.

The most common method of controlling vapor intrusion is to block the migration pathway at the point where vapors enter a building by installing a vapor mitigation system, sometimes called a "Radon System". The most common type of vapor mitigation system, called a sub-slab depressurization system or a sub-slab ventilation system, has been used for many years to prevent radon from infiltrating from soils into buildings, and is also effective for preventing contaminant vapors from entering buildings. The U. S. Environmental Protection Agency (EPA) has developed a number of publications that describe the proper design, installation, and operation of sub-slab depressurization systems. For information on sub-slab depressurization systems IDEM recommends the following EPA publications;

EPA (2003) *Consumer Guide to Radon Reduction*:
Available at: http://www.epa.gov/radon/pubs/consguid.html

EPA (1994) *Radon Mitigation Standards*
Available at: http://www.epa.gov/radon/pubs/mitstds.html

Methods to reduce or prevent vapor intrusion are more effective and easier to install if incorporated into the design of buildings under construction. The following EPA publications and websites are recommended for sites where new building construction is anticipated, and vapor intrusion may be an issue;

The EPA *Radon-Resistant New Construction* webpage (http://www.epa.gov/radon/construc.html)

EPA (2001) *Building Radon Out*
Available at: http://www.epa.gov/radon/construc.html

Other techniques which help to reduce vapor intrusion into buildings include sealing cracks or openings in foundation walls or slabs, sealing open sump pits, and installation of vapor barriers in crawl spaces or over earthen basement floors. These techniques are often performed in conjunction with installation of a sub-slab depressurization system.

Contractors who install radon mitigation systems in residential buildings in Indiana must be certified by the Indiana State Department of Health (ISDH). IDEM recommends that installation of sub-slab depressurization systems for vapor intrusion sites be performed by an ISDH certified contractor. A list of certified contractors can be found at:

http://www.in.gov/isdh/regsvcs/radhealth/radon.htm

A properly installed sub-slab depressurization system does not reduce contaminant concentrations in the source area, but does effectively prevent contaminant vapors from entering occupied structures. IDEM expects that active remediation of the contaminant source area will also be conducted at any site where a sub-slab depressurization system, or other remedial measures, are needed to protect receptors. Because remediation of a contaminant source area may take years to complete, any exposure prevention measures taken, such as installation of sub-slab depressurization system, will require periodic inspection and maintenance to ensure that the systems are operating safely and effectively, and that potential receptors are protected. Inspection of the systems on a quarterly basis is recommended, and the systems should be maintained until the source areas are fully remediated and closed.

Additional information on remedial action for vapor intrusion site can be found in State of New Jersey (2005), and State of California (2005).

10.0 Chlorinated Compounds Technical Basis and Rationale

The pilot program described in this document has two major goals. The first is to provide a default approach to site investigations at potential vapor intrusion sites, and the second is to determine screening levels in the subsurface that are both health protective and reasonable. Indoor air health protective levels can be defined following the risk-based approach outlined by the IDEM RISC program (IDEM, 2001). Reasonable must be defined as health protective, but not so conservatively health protective that the false positive investigation rate becomes economically burdensome to responsible parties. IDEM has attempted to initially define screening levels that minimize the false positive rate and meet the health protective guidelines provided in the Risk Integrated System of Closure (IDEM, 2001). While the pilot program provides a starting point, ultimately the determination of both health protective and reasonable screening levels will require the use of empirical data. The data from site-specific investigations will be collected and analyzed over time. The analyses will allow IDEM to adjust and refine screening levels in the subsurface that are consistent with the goal of "health protective and reasonable."

Default vapor intrusion approaches that are health protective and reasonable are difficult to develop due to a number of issues, including: predicting attenuation in the subsurface environment, indoor air background levels that exceed chronic health protective levels, and reliable soil gas and subslab measurement methods. Developing default screening levels requires an understanding of how these issues complicate default site investigations. For instance, it is difficult to determine if a chronic indoor air problem is caused by vapor intrusion when indoor air measurements frequently exceed chronic health protective levels due to indoor air background levels caused by lifestyle choices.

The development of screening levels for chlorinated compounds recognizes that chlorinated compounds generally do not rapidly biodegrade in the subsurface. If it becomes necessary to investigate soil vapors or sample inside the home, then IDEM has separated corrective action decisions into two groups, those requiring prompt action, and those requiring further investigation to determine if corrective action is warranted. These approaches are consistent with the goal of being health protective and reasonable in a default site investigation process.

10.1 General Program Description

The pilot program approach recommends a sequential site investigation process, beginning with soil and/or ground water screening. If soil or ground water concentrations exceed screening levels, then soil gas or sub-slab vapor samples are collected and compared with screening levels. If soil gas or sub-slab vapor samples exceed screening levels, then indoor air sampling is necessary. Indoor air samples are the only definitive sample that can be used to require corrective action for the vapor intrusion pathway. Assuming the site meets certain qualifying conditions, then the site may be screened out if soil and ground water concentrations are below their screening levels, or if the soil gas or sub-slab results are below their screening values.

Screening levels were developed for four key carcinogenic compounds commonly found at chlorinated sites: 1,2 Dichloroethane (1,2 DCA), tetrachloroethylene (PCE), trichloroethylene (TCE), and vinyl chloride (VC). As carcinogens, these compounds are the primary constituents of concern at chlorinated sites, with health protective concentrations significantly lower than any of the other chlorinated compounds.

A significant problem in development of the default site approach is determining realistic health protective screening levels that account for attenuation known to occur in the subsurface environment. IDEM has used the subsurface attenuation factors presented in the EPA (2002) guidance document.

10.2 Soil Screening Levels

Screening levels for target chlorinated compounds in soils were developed using the Johnson & Ettinger Model (Version 3.0) available from the EPA. IDEM used a one year exposure duration and approximated sources 25 to 100 ft. from a residence, across several soil types with varying organic carbon content from 0.002 to 0.004. These screening levels may be adjusted as site-specific data are collected and evaluated.

The soil screening levels for the target chlorinated compounds in soils are significantly greater than the RISC default industrial closure levels. Therefore, at these concentrations, sites will generally need to undertake source removal or remediation of soils regardless of whether the vapor intrusion pathway is present. However, it is expected that at most sites, ground water concentrations will be used to determine if it is necessary to perform soil gas investigations.

10.3 Ground Water Screening Levels

Screening levels in ground water were developed recognizing that chlorinated contaminants are fairly stable in most subsurface environments. Screening levels in ground water were also developed using health protective indoor air levels as a starting point. For carcinogens, health protective levels in indoor air are based on a 1×10^{-5} risk level, and are dependent on the period of exposure. Therefore, acceptable indoor air concentrations are greater for a short exposure duration than for longer-term exposure. Determining health protective levels for ground water screening values requires an estimate of the amount of time over which exposure is expected to occur, and the average concentration of the contaminant in ground water. IDEM recognizes that it may be difficult to accurately determine exposure durations. Generally, IDEM expects the investigator to use the estimated time of release to help determine the time of exposure. It may also be reasonable to account for a conservative contaminant time of travel to help estimate the exposure duration. If the release date is unknown, IDEM expects the investigator to use the longest reasonable exposure duration.

Acceptable indoor air concentrations have been determined for a series of exposure durations based on residential and commercial exposure scenarios. All residential exposure scenarios used child only or age adjusted exposure assumptions to determine acceptable indoor air levels. Age-adjusted approaches take into account body weights and air intake rates commensurate with the age of the exposed population. For commercial properties, the default exposure durations were used with adult only exposure assumptions at the 1×10^{-5} risk level, to calculate health protective indoor air levels.

Once acceptable indoor air levels were derived, ground water screening levels were back-calculated using the attenuation equation presented in Appendix F of the EPA (2002) guidance document.

$$C_{gw} = \frac{C_{indoor}}{\alpha \ x \ H_c}$$

Where:

C_{gw} = Concentration in ground water (ug/l) x 1000 L/m^3
C_{indoor} = Acceptable indoor air concentration (varies by constituent)
H_c = Henry's Law Constant corrected for ground water temperature
α = Attenuation constant derived from figure 3b of EPA (2002), varying by depth to ground water and soil type

A significant factor in determining reasonable ground water screening levels is the use of a Henry's Law Constant corrected for subsurface temperatures, rather than the widely reported values determined for a temperature of about 25^o C. Correction of Henry's Law for lower temperatures in the subsurface produces higher, although reliable, ground water screening levels.

A series of tables has been developed that list acceptable ground water screening levels for a given length of exposure (1, 5, 10, 20 and 30 years), chlorinated compound, soil type, and depth to ground water. If contaminant concentrations in ground water samples exceed the screening levels based on soil type and depth to ground water, then a soil or sub-slab gas investigation is warranted.

10.4 Soil gas/Sub-slab Screening Levels

If soil or ground water screening levels are exceeded, then soil gas or sub-slab sampling is recommended. Sub-slab sampling procedures recommended by IDEM are presented in DiGiulio (1, 2) and EPA (2006). Where sub-slab is not possible or desired, soil gas sampling is recommended. Recommended soil gas sampling procedures are based on the information provided in API (2004), Hartman (2004) and State of California (2003), and are included in Appendix II.

Soil gas and sub-slab attenuation factors of 0.01 and 0.1, respectively, were based on EPA (2002) guidance. These attenuation factors are empirically derived.

Sub-slab and soil gas screening levels are derived from indoor air levels, multiplied by the appropriate attenuation factor. Two sets of action levels were derived; Prompt Action levels, and Potential Chronic Indicators. Prompt Action levels were calculated using various exposure durations (ED), beginning with a child only exposure scenario for shorter exposure durations, and continuing through age-adjusted exposure scenarios as the exposure duration increased. The Potential Chronic Levels are defined as a range from the one-year exposure duration, child only calculation, up to the limiting (30 year) exposure duration, age-adjusted risk calculation. All risk is calculated at the 1.0 x 10^{-5} risk level using standard EPA inputs for body weight, exposure frequency and inhalation.

IDEM takes the position that risk greater than 1.0 x 10^{-5} requires prompt action. Soil gas or sub-slab gas concentrations exceeding the Prompt Action Levels necessitate immediate action. Prompt sampling of indoor air is recommended. If the sub-slab or soil gas sample results fall within the

Potential Chronic Indicator range, then further investigation is warranted, but indoor air sampling may or may not be indicated.

10.5 Indoor Air Action Levels

If indoor air sampling exceeds the Sub-Chronic action levels presented in Appendix VIII, Table 2 (residential sites) or Table 3 (commercial sites), then immediate corrective action to reduce the exposure is required. This may occur by many different methods, including: prompt installation of a home ventilation or remediation system or other means of reducing exposure. If indoor air samples are within the chronic range of values based on exposure duration, then further investigation is warranted. Further action may include additional indoor air sampling over time or corrective action. The need for further investigation or corrective action will be decided on a case by case basis.

Appendix I

Sub-Slab Sampling Procedures

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Sub-Slab Sampling Procedures

Sub-slab sampling is the term used to describe whole air samples that are collected from immediately below the basement or slab of a building. Evacuated stainless steel canisters, commonly known as "Summa canisters" are used to collect the samples. The process involves drilling one or more holes through the concrete floor; placing a sleeve or probe through the concrete, and then collecting an air sample into the summa canister.

Sub-slab sampling is used to determine whether contaminant vapors exist beneath a building. The presence of contaminant vapors beneath a building provides evidence that the pathway for vapor migration is complete. Sub-slab vapor concentrations exceeding the action levels presented in Appendix VIII indicate the need for further investigation (*e.g.* indoor air sampling), or initiation of corrective action measures to ensure that contaminant vapors do not enter the building.

Although the concept of sub-slab sampling is simple, the actual process has numerous pitfalls and nuances that need to be addressed. The EPA (2006) has developed a recommended series of procedures and a step by step methodology for collection and evaluation of sub-slab samples.

The EPA has released three documents regarding sub-slab sampling. The documents by DiGiulio (1, 2) are draft documents, whereas the EPA (2006) document is the final report on an investigation of sub-slab sampling methodologies, and incorporates the work presented in DiGiulio (1, 2).

IDEM is currently evaluating sub-slab sampling procedures. In the meantime, IDEM recommends that procedures presented in the EPA (2006) report be followed whenever sub-slab sampling is conducted at a potential vapor intrusion site in Indiana.

The EPA report, titled *Assessment of Vapor Intrusion in Homes Near the Raymark Superfund Site Using Basement and Sub-Slab Air Samples*. (EPA/600/R-05/147, March 2006), is available on the internet at:

http://www.epa.gov/ada//pubs/reports/600R05147.html

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Appendix II

Soil Gas Sampling Procedures

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Soil Gas Sampling Procedures

Priority of Soil Gas Sampling Locations

Sub-slab sampling is the preferred technique for evaluating the potential for vapor intrusion into indoor air. However, subslab sampling is more difficult and intrusive and requires greater cooperation from the potentially-affected property owner. In the event that sub-slab soil gas samples cannot be collected, soil gas profiles (samples collected at multiple depths) adjacent and as close as possible to the building of interest should be collected from the up-gradient and down-gradient sides of potentially affected buildings. Soil gas samples collected from multiple depths may not be averaged, nor may up-gradient and down-gradient samples collected around a building be averaged. All soil gas samples should be individually compared to the appropriate screening levels presented in the tables that appear in Appendix VIII.

Indoor air sampling may be necessary in some situations, but usually only after soil gas profiles or subslab sampling have already been performed, and have determined that a vapor intrusion threat may exist. One exception is when contaminant concentrations in groundwater are greater than ten times the screening levels. In this situation, prompt, simultaneous sampling of indoor air and either sub-slab or soil gas sampling is recommended to expedite the evaluation of potential exposure.

Selection of Soil Gas Sampling Locations

Subslab sampling procedures recommended by IDEM are discussed in DiGiulio (1, 2) and EPA (2006). If subslab sampling is performed, special attention should be given to determining the locations of any utilities that may be present beneath the slab. For structures with unfinished basements, it is usually easy to identify where utilities enter and how they are routed through the building. For slab-on-grade construction or structures with finished basements, it may be much more difficult to determine utility locations.

Soil gas profiles are not collected for subslab sampling, however, soil gas profiles collected external to a building may be used in conjunction with subslab sampling if a more detailed evaluation of contaminant concentrations with respect to depth is required.

For soil gas sampling outside of a building of interest, soil gas profiles should be collected as close to the building as possible. As with any subsurface exploration, be aware of utility locations prior to drilling or soil boring activities. Soil gas profiles should be collected from the upgradient and downgradient sides of the building relative to groundwater flow (if groundwater contamination is the suspected source of vapors), or relative to known areas of soil contamination if soil is the suspected source. The API (2004, Section 4.3.1) provides information on soil gas sampling locations. Sampling at multiple depths is preferable for external sampling locations. A lower soil gas sample should generally be collected several feet above the water table; an upper soil gas sample should be collected at a depth of about 5 feet below the base of the adjacent building (below the slab, crawlspace, or basement). If the distance between the upper and lower soil gas samples is greater than approximately 8 feet, an intermediate depth sample should be collected between the upper and lower samples. Soil gas profiles provide information on attenuation or degradation (in the case of petroleum hydrocarbons) of contaminant vapors between the source area and the point of potential exposure.

Soil Gas Sampling Apparatus

For all soil vapor sampling situations, sampling equipment should have the smallest possible internal volume to reduce the need for purging. Minimal purging reduces the risk of inducing air flow from outside the area of interest, and helps preserve sample integrity. In addition, it is important that all connections or fittings in the sampling equipment be tight, and not allow any air leakage into the sample collection container. Leak testing of sampling equipment is briefly discussed by the State of California (2003).

<u>Sample containers:</u> Small-volume Summa canisters (400 ml or 1 Liter) are recommended for soil gas sample collection. The canisters should be equipped with flow regulators and a vacuum gauge. Larger volume Summa canisters should not be used unless time-averaged air samples are being collected (typically for indoor air or sub-slab samples). Other sample containers (e.g. Tedlar bags) should not be used unless the samples are being collected for immediate analysis in an on-site laboratory. If samples must be shipped to an off-site laboratory, only summa canisters should be used for sample collection.

<u>Sample Ports:</u> For soil gas sampling outside of a building, a borehole will have to be created using direct-push methods, hollow-stem auger methods, or hand auger methods. Small-diameter direct-push methods (2-inch borehole or less) are preferred for most situations, as there is less disturbance of surrounding soils. The borehole should extend to just above the saturated zone, with continuous core removal and sample collection. A detailed stratigraphic log should be prepared to identify coarser strata that may be preferential pathways for vapor migration. Special attention should be paid to the moisture content of the soils throughout the soil profile, as the moisture content is a sensitive parameter affecting vapor migration through the subsurface. Observations of soil moisture should be noted on the stratigraphic log for each boring. In addition, the soil cores and samples collected should be screened with an appropriate instrument (PID, FID) to identify potentially contaminated zones or preferential pathways.

Soil gas sampling ports are not the same as groundwater monitoring wells, and monitoring well construction techniques should not be used for soil gas investigations. For collection of soil gas samples, small-diameter stainless-steel screens should be emplaced in the borehole at the appropriate depths. The screens typically should be 6 inches in length, and should not be greater than one foot in length for most situations. Screens should be placed, and vapor samples collected, at approximately 5 feet below the depth of the basement or slab of the building of interest (the upper sample), several feet above the zone of saturation (the lower sample), and at the midpoint between the upper and lower samples. If groundwater is shallow, a midpoint sample may not be necessary. Vapor sample collection depths may also be adjusted based on the strata encountered in the borehole, or vapor screening results discussed above.

Small-diameter (1/4 or 1/8 inch) tubing should be used to connect the screen to the above-ground sampling ports. Nylon, Teflon, or stainless steel tubing is commonly used. Nylon tubing is preferred, as Teflon tubing reportedly sorbs some compounds. 1/8 inch nylon tubing is reportedly easier to work with than 1/4 inch tubing (Hartman, 2004). Tubing should extend one to two feet above the ground surface, and be fitted with a gas-tight valve or cap.

The borehole surrounding the screen should be filled with an appropriately sized sand pack that extends a short distance (six inches to one foot) above the screen. The rest of the borehole should be sealed with hydrated bentonite. In some situations, several screens corresponding to multiple sample depths can be emplaced in one borehole. It is important that the borehole be properly sealed and the screen(s) isolated so that air from the surface or overlying strata cannot infiltrate into the sampling apparatus. The API (2004, Figures C-5 and C-6) presents schematic diagrams of typical vapor-monitoring installations, and photographs of a nested soil gas monitoring point (Figures C-2 through C-4).

Sampling Techniques

For soil gas sampling outside of a building of interest:

Purging: Upon completion of the installation of the sampling port, the volume of air in the sand pack should be calculated. Approximately 3 times this volume of air should be slowly purged immediately after installation and sealing of the sampling port (this should not be a large volume, assuming a small-diameter borehole, a sand pack height of 1 foot or less, and a porosity of about 30% for the sand pack). Samples should not be collected for 24 to 48 hours after installation of the sampling port and purging of the sand pack. Purging should be accomplished using a large graduated syringe or hand-operated vacuum pump. Purge volumes should be recorded and included in the reporting for the soil gas sampling event.

Prior to sample collection, the internal volume of the sampling apparatus, including the implant screen, and the tubing, but excluding the sample container volume and the sand pack volume, must be determined. This is termed the "dead volume" of air in the sampling apparatus, and must be purged prior to sample collection. Approximately 3 times the dead volume should be slowly purged prior to sampling. The number and rate of dead volumes purged should be measured and recorded, and should remain consistent between sample locations.

Sample Collection Rate and Vacuum: The sample collection rate and vacuum should be low to minimize short-circuiting of vapors from outside the area of interest, and to provide representative soil vapor samples. A sampling rate of 100 to 200 ml/minute is recommended (State of California, 2003, Section 2.5). Vacuum during sampling should be as low as possible, less than or equal to 10 inches of water, and should not exceed 50 inches of water. In wet or fine-grained soils, it may be difficult to collect a sample without excessive vacuum. In these situations, a very slow sample rate should be used. Sample collection rate and vacuum readings should be recorded and included in the reporting for the soil gas sampling event.

Leak Detection Testing: For shallow samples (collected at 5 feet below grade or less) or samples where large volumes of vapor are collected (greater than 1 L), leak detection testing may be required to ensure that contaminant concentrations in the sample are not diluted by surface air. Leak detection testing methods are discussed by the State of California (2003, Section 2.4)

Analytical considerations: Please see Appendix VI for all analytical derterminations

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Appendix III

Indoor Air Sampling Considerations

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Indoor Air Sampling Considerations

IDEM is currently developing indoor air sampling procedures. This appendix presents an overview of some of the more relevant indoor air sampling issues that should be considered whenever undertaking indoor air sampling. The user is referred to the references listed below and in Appendix IX for a more complete description of indoor air sampling procedures and recommendations.

Determining if indoor air action levels are exceeded may be difficult. There are inherent problems with sampling the indoor air and also with interpreting the results. For instance, it is easy to locate a sample in areas where the indoor air is not representative, such as where air is diluted by vents or air ducts. It is also easy to encounter elevated indoor air background levels of the contaminant that is being measured. Therefore, it is often advisable to sample under conditions where indoor air action levels are most likely to be exceeded, and to simultaneously investigate contaminant vapor in the soil or directly beneath the building. If sampling is conducted under these "worst case" conditions and action levels are not exceeded, then one can be reasonably sure that there is not an indoor air vapor intrusion problem. However, exceedence of an indoor air action level under "worst case" conditions does not necessarily indicate a vapor intrusion problem. The indoor air data must be interpreted considering the indoor air background levels, and it must be verified that contaminant vapor exists below the structure. The presence of contaminant vapors below a structure indicates that a "completed pathway" exists.

There are two types of background associated with indoor air sampling; indoor air background and ambient background. Either or both background conditions can exceed chronic action levels (but usually not short term action levels). Although there is a simple way to measure ambient background levels, it is difficult to reliably measure indoor air background levels. For these reasons, collection of indoor air data without evidence to indicate the potential for vapor intrusion from subsurface sources is not advised. Indoor air data should be accompanied by subslab or other types of soil gas data to verify that the pathway to indoor air is complete.

To minimize the impact of indoor air background, indoor activities such as smoking, use of sprays and solvents, paints, etc. should be suspended where practical, and if not, should be noted during sampling. Outdoor activities that could influence indoor air levels such as mowing, painting, asphalting, etc. should also be suspended. A good discussion of background levels is contained in EPA (2002) and the Commonwealth of Massachusetts (2002) *Indoor Air Sampling and Evaluation Guide*. Before sampling it is a good idea to review these references.

Sampling under worst case conditions is a matter of where and when to sample. Worst case samples are taken in certain locations and under certain ambient conditions. Worst case samples are generally located in the basements or areas where vapors first enter a home or building. In general, when sampling under worst case conditions, it is recommend that at least three 24 hour samples be taken; one in the basement or assumed worst case location, one in the general living area, and one outdoor ambient background sample. Worst case samples should also be taken under certain ambient conditions. The table below, from the Commonwealth of Massachusetts (2002) *Indoor Air Sampling and Evaluation Guide*, may assist in determining "worst case" ambient sampling conditions.

Parameter	Most conservative conditions	Least conservative conditions
Season	Late winter/early spring	Summer
Temperature	Indoor–10^{o} F >than outdoors	Indoor Temp. < outdoor temp.
Wind	Steady: > approx. 5 mph	Calm
Soil	Saturated with rain	Dry
Doors/Windows	Closed	Open
Mechanical Heating Systems	Operating	Off
Mechanical fans	Off	On

Appendix IV

Indoor Air Building Survey Checklist

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INDOOR AIR BUILDING SURVEY CHECKLIST

Preparer's Name: ________________________ Date: ___________________________

Preparer's Affiliation: ______________________ Phone #: ______________________

Site Name: _____________________________ Site # ________________________

Site Address (include city and zip):____

Part I – Occupants

List of Current Occupants/Occupation (include children)

Name (Age)	Address: (Lot # or apt. #)	Sex (M/F)	Occupation
John Doe (42)	112 South St. Lot # 12	M	geologist

Part II – Building Characteristics

Building type: residential / multi-family residential / office / strip mall / commercial / industrial / other

Describe building: ________________________________ Year constructed: _______________

Sensitive population: day care / nursing home / hospital / school / other (specify): ___________

Number of floors at or above grade: _______

Number of floors below grade: ________ (full basement / crawl space / slab on grade)

Depth of basement below grade surface: ______ ft. Basement size: ______ ft^2

Basement floor construction: concrete / dirt / slab / stone / other (specify): ________

Foundation walls: poured concrete / cinder blocks / stone / other (specify): ___________

Basement sump present? *Yes / No* Sump pump? *Yes / No* Water in sump? *Yes / No*

Significant cracks present in basement floor? *Yes / No*

Significant cracks present in basement walls? *Yes / No*

Are the basement walls or floor sealed with waterproof paint or epoxy coatings? *Yes / No*

Is there a whole house fan? *Yes / No*

Septic system? *Yes / Yes (but not used) / No*

Irrigation/private well? *Yes / Yes (but not used) / No*

Type of ground cover outside of building: grass / concrete / asphalt / other (specify) __________

Sub-slab vapor/moisture barrier in place? *Yes / No / Don't know*
Type of barrier: ___________________________

Type of heating system (circle all that apply):
hot air circulation hot air radiation wood steam radiation
heat pump hot water radiation kerosene heater electric baseboard
other (specify): ________________________

Type or ventilation system (circle all that apply):
central air conditioning mechanical fans bathroom ventilation fans
individual air conditioning units kitchen range hood fan outside air intake
other (specify): __________________

Type of fuel utilized (circle all that apply):
Natural gas / electric / fuel oil / wood / coal / solar / kerosene / other (specify):__________

Part III – Outside Contaminant Sources

Contaminated site within 50-ft (BTEX) or 100-ft (Chlorinated)? ______________________

If yes: Site Name: _________________ Site Number:___________________________

Other stationary sources nearby (gas stations, emission stacks, etc.): _________________________

Heavy vehicular traffic nearby (or other mobile sources): __________________________________

Part IV – Indoor Contaminant Sources

Identify all potential indoor sources found in the building (including attached garages), the location of the source (floor & room), and whether the item was removed from the building 48 hours prior to the indoor air sampling event. Any ventilation implemented after removal of the items should be completed at least 24 hours prior to the start of the indoor air sampling event.

Potential Sources	**Location (s)**	**Removed** (Yes / No / NA)
Gasoline storage cans		
Gas-powered equipment (mowers, etc)		
Kerosene storage cans		
Paints / thinners / strippers		
Cleaning solvents		
Oven cleaners		
Carpet / upholstery cleaners		
Other house cleaning products		
Moth balls		
Polishes / waxes		
Insecticides		
Furniture / floor remover		
Nail polish / polish remover		
Hairspray		
Cologne / perfume		
Air fresheners		
Fuel tank (inside building)		NA
Wood stove or fireplace		NA
New Furniture / upholstery		
New carpeting / flooring		NA
Hobbies – glues, paints, lacquers, photographic darkroom chemicals, etc		
Scented trees, wreaths, potpourri, etc.		
Other (specify):		

Part V – Miscellaneous Items

Do any occupants of the building smoke? *Yes / No* How often? _______________

Last time someone smoked in the building? __________________ hours / days ago

Does the building have an attached garage directly connected to living space? *Yes / No*

If so, is a car usually parked in the garage? *Yes / No*

Are gas-powered equipment or cans of gasoline/fuels stored in the garage? *Yes / No*

Do the occupants of the building have their clothes dry cleaned? *Yes / No*

If yes, how often? Weekly / monthly / 3-4 times a year

When was the last dry cleaned garment brought home? ________________

Do any of the occupants use solvents in work? *Yes / No*

If yes, what types of solvents are used? ___________________________________

If yes, are their clothes washed at work? *Yes / No*

Have any pesticides/herbicides been applied around the building or in the yard? *Yes / No*

If so, when and which chemicals? ____

Has there ever been a fire in the building? *Yes / No* If yes, when? ____________

Has painting or staining been done in the building in the last 6 months? *Yes / No*

If yes, when? _______________ and where? __________________________

Part VI – Sampling Information

Company/Consultant: _____________________________ Phone number: ( ) ____ - ________

Sample Source: Indoor Air / Sub-Slab / Near Slab Soil Gas / Exterior Soil Gas

Sampler Type: 400 mL – 1.0 L Summa Canister / 6 L Summa Canister / Other (specify): ______________________

Analytical Method: TO-14A / TO-15 / TO-15 SIM / other: __________

Laboratory: ___________________________

Sample locations (floor, room):

Field/Sample ID# _________________________ Field/Sample ID # _____________________

Field/Sample ID# _________________________ Field/Sample ID # _____________________

Field/Sample ID# _________________________ Field/Sample ID # _____________________

Were "Instructions for Occupants" followed? *Yes / No*

If not, describe modifications: ____

Provide Drawing of Sample Location (s) in Building

Part VII – Metrological Conditions

Was there significant precipitation within 12 hours prior to (or during) the sampling event?
Yes / No

Describe the general weather conditions: ____

____

Part VIII – General Observations

Provide any information that may be pertinent to the sampling event and may assist in the data interpretation process.

____

____

____

Recommended Instructions for Residents

The following is a suggested list for residents to follow (to the extent practical) in order to reduce interference in obtaining representative samples. IDEM suggests that these items be followed starting at least 48 hours prior to and during the sampling event.

- Do not open windows, fireplace opening or vents
- Do not keep doors open.
- Do not operate ventilation fans.
- Do not use air fresheners or odor eliminators.
- Do not smoke in the house to the extent practical.
- Do not use wood stoves, fireplace or auxiliary heating equipment (e.g., kerosene heater)
- Do not use paints or varnishes.
- Do not use cleaning products (e.g., bathroom cleaners, furniture polish, appliance cleaners, and floor cleaners).
- Do not use cosmetics, including hair spray, nail polish, nail polish remover, perfume, etc.
- Do not partake in indoor hobbies that use solvents.
- Do not apply pesticides.
- Do not store containers of gasoline, oil or petroleum-based or other solvents within the house or attached garage (except for fuel oil tanks).
- Do not operate or store automobiles in an attached garage.

Appendix V

Evaluation of Industrial Sites

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Evaluation of Industrial Sites

Introduction

This Pilot Program Guidance (PPG) is applicable when vapor intrusion from benzene or chlorinated compounds is suspected at non-residential sites. There are three types of sites: residential, commercial, and industrial. Residential sites include homes, apartments, and dwellings where children may live. Commercial sites include typical workplaces such as offices and other businesses where exposure to vapor phase contaminants is not expected based on normal operations and which are not generally regulated by the Occupational Safety and Health Administration (OSHA). Industrial sites include manufacturing facilities and other workplaces where exposure to vapor phase contaminants could be expected based on normal operations and which are regulated by OSHA. Draft screening levels for groundwater, soil gas samples, sub-slab gas samples, and OSHA indoor air levels for industrial sites are listed in Table 1 below. IDEM recommends the following pilot approach to investigating non-residential sites.

OSHA Considerations

The Occupational Safety and Health Act of 1970 (OSHA) uses Permissible Exposure Limits (PELs) to regulate work place exposure to chemicals. OSHA PELs are not based solely on risk, but are adjusted to account for other factors including economic feasibility. IDEM has established draft health based screening levels that are based upon different exposure assumptions, and for most hazardous chemicals, the IDEM screening levels are well below the OSHA PELs. This guidance is intended to help determine where OSHA PELs apply and where IDEM screening levels apply. It is important to note that the indoor air action levels, either OSHA PELs or IDEM's action levels, are used to determine the appropriate abatement and remediation response and are not enforced by IDEM, in and of themselves.

The following provides recommendations for when to apply IDEM indoor air action levels or OSHA PELs:

- If workers are exposed to vapors from a subsurface source of contamination regulated by IDEM (regardless of whether contamination is derived from that facility or another) and workers are simultaneously exposed to the same hazardous vapors in the work place (*e.g.* a vapor degreaser) and the workers are knowledgeable of their exposures *via* an OSHA hazard communication program, then the exposure is regulated under OSHA. The OSHA PELs should be used for evaluating any necessary response actions relative to the indoor air concentrations, but the environmental remediation (soil or groundwater clean-up) should be based upon IDEM's RISC closure levels, which are listed in Appendix 1, Table A of the *RISC Technical Resource Guidance Document* (IDEM, 2001).

- If workers are exposed to vapors from subsurface contamination and are simultaneously exposed to different hazardous chemicals in the work place, and the workers are knowledgeable of their exposures *via* an OSHA hazard communication program, then the exposure associated with the release would be managed in accordance with IDEM's health based screening levels. However, the employer of the affected facility has the option of incorporating the additional environmental exposure into their employee hazard communication program (*i.e.* inform staff of their exposure and provide appropriate monitoring and/or protection), in which case all OSHA requirements and PELs would apply. Response actions relative to the indoor air concentrations will be based upon which set of standards are applied (PELs or IDEM action levels), but the environmental remediation (soil or groundwater clean-up) should be based upon IDEM's RISC closure levels, which are listed in Appendix 1, Table A of the *RISC Technical Resource Guidance Document* (IDEM, 2001).

- Workers in a non-industrial portion of a site where exposure to a hazardous vapor is part of the normal operating conditions at a different location (*e.g.* office staff associated with manufacturing operations), are covered by this guidance, and IDEM's health based indoor air action levels. The employer of the affected facility has the option of incorporating the environmental exposure into their employee protection program (*i.e.* inform the staff of their exposure and provide appropriate monitoring and/or protection), in which case all OSHA requirements and PELs would apply. Response actions relative to the indoor air concentrations should be based upon which set of standards are applied (PELs or IDEM action levels), but the environmental remediation (soil or groundwater clean-up) should be based upon IDEM's RISC default or non-default closure procedure which are listed in the *RISC Technical Resource Guidance Document* (IDEM, 2001).

- If workers are exposed to vapors from subsurface contamination that is not associated with the normal operating conditions of that work place (*e.g.* a retail operation or daycare center), then the exposure and any remedial action should be managed in accordance with this policy and IDEM's health based indoor air action levels.

The first three examples pertain primarily to the combination of environmental and occupational exposures within industrial workplaces resulting from the release of contaminants into the subsurface soil and/or ground water. IDEM recommends that the health based indoor air action levels presented in this guidance be applied in all other scenarios, particularly where employees within buildings have not voluntarily accepted a risk associated with chemical exposure in connection with their employment.

The health protective indoor air action levels for a non-residential property other than an industrial facility (*i.e.* commercial facilities) appear in Appendix VIII, Table 3. The health protective levels may vary depending on the exposure duration and the presence of sensitive sub-populations.

Notification

When IDEM suspects or confirms that vapors from a chemical release to the environment have intruded into an indoor air space, then it is recommended that the affected business be notified by letter, with copies of the letter sent to the Potentially Responsible Party, the State Department of Health, the local health department, and IOSHA.

Preliminary Screening

The approach for evaluation of industrial properties follows the screening evaluations described in Part A (BTEX Sites) and Part B (Chlorinated Sites) of the Pilot Program Guidance.

Preliminary screening is undertaken to determine if concentrations in the groundwater or soil are above action levels, or if preferential pathways exist. There should be sufficient information available to make these initial determinations from soil and ground water sampling data and other site information. Some things to be considered before taking indoor air samples are:

1. What are the contaminants of concern at the site, and are chlorinated compounds (PCE, TCE, 1,2-DCA or VC) or benzene present? Is indoor air exposure possible within 50 feet of the source for benzene or 100 feet for chlorinated compounds?

2. Do immediate threats, such as fire/explosion, exist? If yes, then the investigator should address these threats first (this guidance does not address fire and explosion issues).

3. Are there noticeable petroleum or solvent odors or complaints of petroleum or solvent odors? If these conditions exist then sample indoor air promptly

4. Is ground water present within five feet of the basement, slab or ground surface? If so then this guidance does not apply. Do preferential pathways exist, (*e.g.* sewer lines, utility conduits, sand lenses, *etc*.)? If yes, then investigate to determine if indoor air sampling is warranted.

Groundwater Screening

If contaminant concentrations in groundwater are above the screening levels listed in Table 1, then there is reason to suspect that contaminant concentrations in indoor air may be above health protective levels. Alternatives to the use of the IDEM default screening levels may be proposed if it can be adequately demonstrated using site-specific data that the alternative screening levels are protective of human health, and will not allow vapor intrusion into nearby structures.

Table 1
Screening Levels for Groundwater, Soil Gas, and Sub-Slab Samples, and OSHA Indoor Air PELs

Contaminant	CAS	GW Screening Levels	Soil Gas Screening Levels	Sub Slab Screening Levels	OSHA Indoor Air PELs
Benzene	71-43-2	22 mg/l	320 mg/m^3 100 ppmv	32 mg/m^3 10 ppmv	3.2 mg/m^3 1 ppmv
1,2 DCA	107-06-2	7900 mg/l	20,000 mg/m^3 5000 ppmv	2,000 mg/m^3 500 ppmv	200 mg/m^3 50 ppmv
PCE	127-18-4	200* mg/l	68,000 mg/m^3 10,000 ppmv	6,800 mg/m^3 1000 ppmv	680 mg/m^3 100 ppmv
TCE	79-01-6	1100* mg/l	54,000 mg/m^3 10,000 ppmv	5400 mg/m^3 1000 ppmv	540 mg/m^3 100 ppmv
VC	75-01-4	3 mg/l	260 mg/m^3 100 ppmv	26 mg/m^3 10 ppmv	2.6 mg/m^3 1 ppmv

* RISC solubility level

Soil Contamination Screening

At this time, IDEM is attempting to determine appropriate industrial soil screening levels using site-specific data. In the interim, prompt source removal should be undertaken at sites where it is expected that soil contamination may cause indoor air contamination above health protective levels. If an indoor air problem is suspected, then the preferred approach is to collect sub-slab samples. If that is not possible, then soil gas sampling may be used, but it is not as definitive as sub-slab sampling. Sub-slab sampling procedures are included in Appendix I, and soil gas sampling procedures are discussed in Appendix II. The number and location of sampling probes needs to be determined on a site specific basis. Alternatives to the use of the default screening levels may be proposed if it can be adequately demonstrated using site-specific data that the alternative screening levels are protective of human health, and will not allow vapor intrusion into nearby structures above health protective levels.

Sub-slab Sampling

Sub-slab sampling is the second step in evaluating sites for vapor intrusion. If a site fails groundwater screening, or there is reason to suspect soil contamination will result in contaminant concentrations in indoor air above health protective levels, then sub-slab sampling is recommended. Sub-slab samples are soil vapor samples taken from directly under the basement or slab collected into an evacuated polished stainless steel canister (a Summa canister). Sub-slab sampling measures the potential for vapor intrusion, but is not definitive evidence that soil gas is entering the facility above health protective levels. Only indoor air samples are definitive. Sub-slab sampling procedures are presented in Appendix I. Once the sub-slab vapor concentration has been determined, it is multiplied by a conservative attenuation factor to predict what the indoor air concentration may be. IDEM has chosen an attenuation factor of 0.1 (10X attenuation of the soil gas into the indoor air), based upon the latest recommendations of EPA (EPA, 2002). If a sub-slab concentration exceeds the screening levels in Table 1, then prompt action should be taken to sample the indoor air. Alternatives to the use of the default screening levels may be proposed if it can be adequately demonstrated using site-specific data that the alternative screening levels are protective of human health, and will not allow vapor intrusion into nearby structures above health protective levels.

Soil Gas Sampling

When it is not possible to obtain sub-slab samples, then soil gas samples from soil gas monitoring points are recommended. The appropriate monitoring point construction and sampling methods are described in Appendix II. It is generally recommended that samples be taken from at least two depths, and at points located on the upgradient and downgradient sides of the potentially affected building. The shallow depth sample should be no less than five feet below the ground surface (bgs), in the case of slab construction, or five feet below the basement floor. Samples taken from shallower depths may encounter significant problems with entraining surface air into the sample (as well as other effects) and are discouraged. The deep sample should be collected several feet above the water table.

The appropriate default attenuation factor for the soil gas samples is 0.01. If concentrations of benzene or a chlorinated compound in soil gas exceed the screening levels in Table 1, then prompt action should be taken to sample the indoor air. Alternatives to the use of the default screening levels may be proposed if it can be adequately demonstrated using site-specific data that the alternative screening levels are protective of human health, and will not allow vapor intrusion into nearby structures above health protective levels.

Indoor Air Sampling

The user is referred to Appendix III for indoor air sampling guidance. This appendix gives some basic guidelines and refers the user to more complete guidance available at other web sites. Indoor air levels should not exceed the levels indicated in Table 1.

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Appendix VI

Analytical Methods

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Analytical Methods Guidance for Vapor Intrusion Sites

Introduction

The availability of a reliable, accurate, and precise sampling method for VOCs in indoor air, sub-slab, or soil-gas is necessary in order to help determine whether the vapor pathway is complete. The canister-based monitoring method for VOCs has proven to be a viable and widely used approach that is based on research and evaluation performed since the early 1980s. The collection of ambient/interior air samples in canisters provides a number of advantages: (1) convenient integration of ambient/interior samples over a specific time period (e.g., 24 hrs); (2) remote sampling and central analysis; (3) ease of storing and shipping samples; (4) unattended sample collection; (5) sufficient volume to allow assessment of measurement precision and/or accuracy of samples by several analytical systems; (6) storage stability for many VOCs over periods of up to 30 days; and (7) sub-ppbv detection limits.

Analytical Methods and Analytes

The analytical methods appropriate for analyzing soil gas, sub-slab, or indoor air samples will depend on the sampling methods and the data quality objectives for the site. It is possible that two different levels of analytical precision may be required; for example, the analysis of specific chemicals of concern may require a more stringent level of quantification than the analysis of fixed and respiration gases (e.g., oxygen, carbon dioxide, methane). It is important, however, that the analytical methods used are consistent within each sampling event. In addition, the stringent analytical requirements for specific chemicals of concern may preclude the use of many field-monitoring devices commonly used to evaluate soil gas [(e.g., hand-held photo-ionization detector (PID), flame-ionization detector (FID), and explosimeter] as these do not provide the necessary accuracy or specificity.

Since significant decisions are made based on the soil gas, sub-slab, and/or indoor air concentrations collected at contaminated sites, it is imperative that the soil gas data reported to IDEM are consistently of high quality. The following will assist in producing results of high quality.

Analytical Method Selection

There are a number of different analytical methods that can be applied to quantify concentrations of chemicals of concern in soil gas, sub-slab, and indoor air samples. However, the particular method selected will depend on the use of the data. Analytical methods that are appropriate are presented in the Section entitled, Sample Containers and Analytical Methods. If another method is chosen then it should be approved by the Indiana Department of Environmental Management prior to being utilized.

Chemicals of Concern

For BTEX sites, analysis should include the full list of analytes as listed in EPA Method TO-15 as well as oxygen, carbon dioxide, and methane (which should be measured to evaluate biodegradation processes in the subsurface).

For Chlorinated sites, the analysis should include the full list of analytes listed in EPA Method TO-15. This list may vary according to the specific goals of the sampling project, the analytical methodology and the laboratory performing the analysis. Analysis of oxygen, carbon dioxide, methane and TPH is not necessary.

Reporting Limits for Vapor Intrusion Sampling

For BTEX sites, the following reporting limits for benzene should be attained to meet the general requirements of the project:

- For soil gas samples, the reporting limit for benzene should be 230 $\mu g/m^3$ (72 ppbv) or less.
- For sub-slab samples, the reporting limit for benzene should be 23 $\mu g/m^3$ (7.2 ppbv) or less.
- For indoor air samples, the reporting limit for benzene should be 2.3 $\mu g/m^3$ (0.72 ppbv) or less.

For Chlorinated sites, the acceptable reporting limits are dependent on the exposure duration. Please see Appendix VIII, Table 7, Residential Screening Levels for Chlorinated Compounds, or Table 8, Commercial Screening Levels for Chlorinated Compounds in order to determine the acceptable reporting limits. In order to determine acceptable reporting limits for soil gas sampling see Appendix VIII, Table 7, Residential Screening Levels for Chlorinated Compounds, or Table 8, Commercial Screening Levels for Chlorinated Compounds, and to determine the reporting limits for indoor air sampling see Appendix VIII, Table 2, Indoor Air Action Levels – Residential, or Table 3, Indoor Air Action Levels – Commercial.

Sample Containers and Analytical Methods

The sample containers recommended for the collection of sub-slab and/or soil-gas samples are stainless steel canisters. Either 400-mililiter, 1-Liter or 6-Liter canisters may be employed. Indiana Department of Environmental Management (IDEM) recommends that the smaller sample containers be utilized for soil-gas and sub-slab sampling to avoid short-circuiting or dilution of the sample with atmospheric air. It should be noted that when sub-slab samples will be collected in conjunction with indoor air samples over a 24-hour period, then a 6-Liter canister is acceptable. Sub-slab and/or soil-gas samples should be analyzed using USEPA Method TO-14A, TO-15, or TO-15 SIM when stainless steel canisters are employed.
Sample containers other than stainless steel canisters can be employed only when screening or preliminary results are appropriate. Other sampling containers such as Tedlar bags or 60 – 500 cubic centimeter (cc) syringes can be used. If either the Tedlar bag or syringe is used the sample should be analyzed immediately after sample collection using a field gas chromatograph (GC) or mobile laboratory. It should be noted that the holding time for Tedlar bags and syringes should not exceed 1 hour. The most common method utilized for field screening of soil gas samples is USEPA SW-846 Method 8260B. The reporting limit should meet the appropriate screening levels as previously discussed.

If soil-gas or sub-slab samples will be collected for oxygen, carbon dioxide, and/or methane the analytical method recommended is Method 3C. These parameters may also be analyzed using field instrumentation.

If the purpose of the near slab soil gas or sub-slab sampling is a stand alone assessment of the vapor intrusion pathway, a fixed laboratory should be employed. At this time, that would require the samples be analyzed with USEPA Method TO-14A, TO-15, or TO-15 SIM.

Data Quality and Reporting

The accuracy of an analytical method is dependent on the handling and preparation of the sample and the maintenance of the analytical equipment. Most analytical methods prescribe minimum quality control measures that are designed to monitor the performance of the analytical procedures. However, additional quality control measures can be implemented by the laboratory or the analyst. At a minimum, the data quality documentation for laboratory analysis should include sample collection records, case narrative, chain of custody, laboratory recorded information on initial and final pressure of canisters, holding time requirements, instrument tuning, instrument calibration records, initial and continuing calibration verifications, laboratory control samples, method blank, internal standards, surrogate recoveries, matrix spike samples and raw data (i.e. chromatograms and mass spectra).

Also, field sheets and maps providing information on sample location and collection procedures should be provided. Include any field measurements and results of any leak tests and any field QA/QC samples such as field duplicates, field blanks, and background samples. A field duplicate should be collected for every twenty samples. A field blank should be collected once per day or once for every twenty samples. A background sample should be collected as recommended in the guidance.

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Appendix VII

Reporting Results to IDEM

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Reporting Results to IDEM

Introduction

There are two types of data submittals requested for vapor intrusion investigations. One data submittal type is contained in the Vapor Intrusion Investigation Form (VIIF). The second type of data submittal is lab analytical data. The VIIF is available in spreadsheet format from the website at:

http://www.in.gov/idem/land/risc/index.html

Digital data submissions are also requested for all analytical data. Guidelines for digital data submission will be posted on the IDEM web page at:

http://www.in.gov/idem/land/datasubmittal/digdatasubmittal.html

In general, the VIIF contains information regarding site source, building information, sampling types, sample location, and results. The VIIF includes an instruction sheet with submittal instructions.

The reporting guidelines for site-specific vapor data are not solely for the evaluation of vapor intrusion (VI). Currently, gathering site-specific vapor intrusion information is necessary for further development of the vapor intrusion pilot program. You do not have to participate, however; your information is valuable to us and your participation would be greatly appreciated. If you choose not to participate, contact the IDEM project manager (PM) for reporting guidelines.

Investigation and Gathering of Analytical Data

The IDEM project manager should be consulted from the start of the planning process for any vapor intrusion investigation. The inclusion of the IDEM PM from the onset of the investigation provides the advantage of a preliminary data review that allows for feedback while the investigation is on-going. This helps determine additional data needs while planning the investigation, and improves the quality of data for risk assessment.

It is important that a VI investigation have representative sampling and analysis that will satisfy the performance objectives determined during the planning process. If the sampling design is representative, the type and amount of contamination present can be reliably determined. Sampling procedures are provided in Appendices I, II, and III of this guidance.

All sampling and analysis procedures should be performed in accordance with the data quality objectives (DQOs) discussed in Appendix 6 of the RISC Technical Resource Guidance Document (IDEM, 2001). Routine reports and documents should comply with all documentation guidelines specified in Appendix 6 of the guidance document. Quality Assurance/quality control (QA/QC) documentation should include: raw data, chromatograms, recorder outputs, mass spectra, computer printouts, charts, graphs, bench sheets, and any other hard copies generated during sampling and analysis. QA/QC documentation should be provided for all analytical work performed throughout the project.

Data Reporting

IDEM is requesting all analytical data be provided directly from the laboratory performing the analysis. Data packages produced by the laboratories should contain all the documents that were produced or used by the laboratory for that particular analysis. Raw data should be provided by the laboratory for all laboratory quality control samples, blanks, spikes, duplicates, standards, and field samples.

Leaking Underground Storage Tank Sites

For sites under the Leaking Underground Storage Tank (LUST) program completing a VIIF is not necessary. Instead, please complete the Vapor Intrusion (VI) sheets included in the Further Site Investigation (FSI) form. This form can be found on the LUST website at:

http://www.in.gov/idem/land/lust/index.html

Additional Common Reporting Needs

All maps, figures, drawings, cross-sections, aerial photographs, and other information should also be submitted in the investigation report or work plan. The maps, drawings, and other items should include suitable scales, compass directions, and clearly illustrated legends. Figures should also be provided for sites where the current conditions do not accurately reflect conditions that existed at the time of the spill or release because of building renovations, underground storage tank (UST) system upgrades, and other changes. All maps and information on the maps should be legible and reproducible. Maps and figures should identify, at a minimum; sampling locations (with analytical results), locations of surrounding properties and potential receptors, and identification of any possible preferential pathways (utility corridors, etc.).

Appendix VIII

Tables

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Appendix VIII – Tables

Table 1
Screening Levels for Benzene

Ground Water Screening Levels for Benzene (μg/l)

Residential

Residential Short Term		Depth to Ground Water 5ft	10ft	15ft
Soil Type	Sand	95	100	120
	Loamy Sand	200	220	230
	Sandy Loam	490	500	520
	Loam	790	820	850

Commercial

Commercial Short Term		Depth to Ground Water 5ft	10ft	15ft
Soil Type	Sand	300	340	400
	Loamy Sand	670	700	740
	Sandy Loam	1600	1600	1700
	Loam	2600	2700	2800

Prompt Action/Potential Chronic Vapor Screening Levels for Benzene

Residential	Vapor Screening Level: Prompt Action	Potential Chronic
Sub-Slab	140 μg/m^3	25-140 μg/m^3
	44 ppbv	7.8-44 ppbv
Crawl Space	14 μg/m^3	2.5-14 μg/m^3
	4.4 ppbv	.78-4.4 ppbv
Soil Gas	1400 μg/m^3	250-1400 μg/m^3
	440 ppbv	78-440 ppbv

Commercial	Vapor Screening Level: Prompt Action	Potential Chronic
Sub-Slab	440 μg/m^3	53-440 μg/m^3
	140 ppbv	17-140 ppbv
Crawl Space	44 μg/m^3	5.3-44 μg/m^3
	14 ppbv	1.7-14 ppbv
Soil Gas	4400 μg/m^3	530-4400 μg/m^3
	1400 ppbv	170-1400 ppbv

Appendix VIII – Tables

Table 2
Indoor Air Action Levels - Residential

Contaminant	CAS	Biodeg?	Sub-Chronic		Chronic							
			1 year		5 years		10 years		20 years		30 years	
			ug/m^3 (ppbv)		ug/m^3 (ppbv)		ug/m^3 (ppbv)		ug/m^3 (ppbv)		ug/m^3 (ppbv)	
Acetone (2-Propanone)	67-64-1	Yes	3300 (1400) (NC)									
Acrolein	107-02-8	Yes	.021 (.0091) (NC)									
Aldrin	309-00-2	No	.047 (.0031)	(NC)	.013 (.00086)	(C)	.0078 (.00052)	(C)	.0054 (.00036)	(C)	.0039 (.00026)	(C)
Benzene	71-43-2	Yes	14 (4.2) (C)				2.5 (.78) (C)					
Bis(2-chloro-1-methylethyl) ether	108-60-1	No	31 (4.5)	(C)	6.3 (.89)	(C)	3.8 (.54)	(C)	2.6 (.37)	(C)	1.9 (.27)	(C)
Bis(2-Chloroethyl)ether	111-44-4	No	.91 (.16)	(C)	.18 (.031)	(C)	.11 (.019)	(C)	.076 (.013)	(C)	.056 (.0095)	(C)
Bis(2-chloroisopropyl)ether	39638-32-9	No	31 (4.5)	(C)	6.3 (.89)	(C)	3.8 (.54)	(C)	2.6 (.37)	(C)	1.9 (.27)	(C)
Bromodichloromethane	75-27-4	No	18 (2.6)	(C)	3.5 (.53)	(C)	2.1 (.32)	(C)	1.5 (.22)	(C)	1.1 (.16)	(C)
Bromoform(tribromomethane)	75-25-2	No	280 (27)	(C)	56 (5.4)	(C)	34 (3.3)	(C)	23 (2.3)	(C)	17 (1.7)	(C)
n-Butanol	71-36-3	No			9.5 (3.1)	(NC)	9.5 (3.1)	(NC)	9.5 (3.1)	(NC)	9.5 (3.1)	(NC)
Carbon disulfide	75-15-0	No			730 (230)	(NC)	730 (230)	(NC)	730 (230)	(NC)	730 (230)	(NC)
Carbon tetrachloride	56-23-5	No	21 (3.3)	(C)	2.6 (.41)	(NC)	2.5 (.4)	(C)	1.7 (.27)	(C)	1.3 (.2)	(C)
Chlordane	12789-03-6	No	3.1 (.19)	(C)	.63 (.037)	(C)	.38 (.023)	(C)	.26 (.016)	(C)	.19 (.011)	(C)
Chlorobenzene	108-90-7	No			62 (13)	(NC)	62 (13)	(NC)	62 (13)	(NC)	62 (13)	(NC)
Chloroethane	75-00-3	No	380 (140)	(C)	76 (29)	(C)	46 (17)	(C)	31 (12)	(C)	23 (8.8)	(C)
Chloroform	67-66-3	No	14 (2.8)	(C)	2.7 (.55)	(C)	1.6 (.34)	(C)	1.1 (.23)	(C)	.83 (.17)	(C)
2-Chlorophenol	95-57-8	No	78 (15)	(NC)	18 (3.5)	(NC)	18 (3.5)	(NC)	18 (3.5)	(NC)	18 (3.5)	(NC)
Cyclohexane	110-82-7	No			6200 (1800)	(NC)	6200 (1800)	(NC)	6200 (1800)	(NC)	6200 (1800)	(NC)
DDD	72-54-8	No	4.6 (.35)	(C)	.91 (.07)	(C)	.55 (.042)	(C)	.38 (.029)	(C)	.28 (.021)	(C)
1,2-Dibromoethane	106-93-4	No	.52 (.068)	(C)	.1 (.014)	(C)	.063 (.0082)	(C)	.043 (.0057)	(C)	.032 (.0041)	(C)
1,2-Dichlorobenzene	95-50-1	No			210 (35)	(NC)	210 (35)	(NC)	210 (35)	(NC)	210 (35)	(NC)
1,3-Dichlorobenzene	541-73-1	No			110 (18)	(NC)	110 (18)	(NC)	110 (18)	(NC)	110 (18)	(NC)
1,4-Dichlorobenzene	106-46-7	No	50 (8.3)	(C)	10 (1.7)	(C)	6 (1)	(C)	4.1 (.69)	(C)	3 (.51)	(C)
1,1-Dichloroethane	75-34-3	No			510 (130)	(NC)	510 (130)	(NC)	510 (130)	(NC)	510 (130)	(NC)
1,2-Dichloroethane	107-06-2	No	12 (3)	(C)	2.4 (.59)	(C)	1.5 (.36)	(C)	1 (.25)	(C)	.74 (.18)	(C)
1,1-Dichloroethylene	75-35-4	No			210 (52)	(NC)	210 (52)	(NC)	210 (52)	(NC)	210 (52)	(NC)
cis-1,2-Dichloroethylene	156-59-2	No			37 (9.2)	(NC)	37 (9.2)	(NC)	37 (9.2)	(NC)	37 (9.2)	(NC)
trans-1,2-Dichloroethylene	156-60-5	No			73 (18)	(NC)	73 (18)	(NC)	73 (18)	(NC)	73 (18)	(NC)
2,4-Dichlorophenoxyacetic acid (2,4-D)	94-75-7	No			37 (4)	(NC)	37 (4)	(NC)	37 (4)	(NC)	37 (4)	(NC)
1,2-Dichloropropane	78-87-5	No	16 (3.5)	(C)	3.2 (.7)	(C)	2 (.42)	(C)	1.3 (.29)	(C)	.98 (.21)	(C)
1,3-Dichloropropene	542-75-6	No	8.9 (2)	(NC)	16 (3.5)	(C)	9.5 (2.1)	(C)	6.5 (1.4)	(C)	4.8 (1.1)	(C)

Appendix VIII – Tables

Table 2
Indoor Air Action Levels - Residential

			Sub-Chronic		Chronic							
			1 year		5 years		10 years		20 years		30 years	
Contaminant	CAS	Biodeg?	ug/m^3 (ppbv)		ug/m^3 (ppbv)		ug/m^3 (ppbv)		ug/m^3 (ppbv)		ug/m^3 (ppbv)	
N,N Dimethylformamide	68-12-2	No			31 (10)	(NC)	31 (10)	(NC)	31 (10)	(NC)	31 (10)	(NC)
Ethyl acetate	141-78-6	No			3300 (910)	(NC)	3300 (910)	(NC)	3300 (910)	(NC)	3300 (910)	(NC)
Ethylbenzene	100-41-4	Yes	1900 (450) (NC)				1100 (240) (NC)					
beta-HCH(beta-BHC)	319-85-7	No	.58 (.048)	(C)	.12 (.0097)	(C)	.07 (.0059)	(C)	.048 (.004)	(C)	.035 (.003)	(C)
Heptachlor	76-44-8	No	.24 (.016)	(C)	.048 (.0031)	(C)	.029 (.0019)	(C)	.02 (.0013)	(C)	.015 (.00095)	(C)
Hexachloroethane	67-72-1	No	78 (8.1)	(C)	3.6 (.38)	(NC)	3.6 (.38)	(NC)	3.6 (.38)	(NC)	3.6 (.38)	(NC)
n-Hexane	110-54-3	No			210 (59)	(NC)	210 (59)	(NC)	210 (59)	(NC)	210 (59)	(NC)
Isopropylbenzene (Cumene)	98-82-8	No			400 (82)	(NC)	400 (82)	(NC)	400 (82)	(NC)	400 (82)	(NC)
Methyl bromide (bromomethane)	74-83-9	No			5.1 (1.3)	(NC)	5.1 (1.3)	(NC)	5.1 (1.3)	(NC)	5.1 (1.3)	(NC)
Methyl ethyl ketone (MEK)	78-93-3	Yes					5100 (1700) (NC)					
Methyl tertiary butyl ether (MTBE)	1634-04–4	No	1200 (330)	(C)	240 (67)	(C)	150 (41)	(C)	100 (28)	(C)	74 (20)	(C)
4-Methyl-2-pentanone (MIBK)	108-10-1	Yes					3100 (770) (NC)					
Methylene chloride	75-09-2	No	680 (200)	(C)	140 (39)	(C)	83 (24)	(C)	57 (16)	(C)	42 (12)	(C)
2-Methylphenol(o-cresol)	95-48-7	No			180 (41)	(NC)	180 (41)	(NC)	180 (41)	(NC)	180 (41)	(NC)
Phenol	108-95-2	Yes					1100 (280) (NC)					
n-Propylbenzene	103-65-1	No			150 (30)	(NC)	150 (30)	(NC)	150 (30)	(NC)	150 (30)	(NC)
Styrene	100-42-5	Yes					1100 (250) (NC)					
1,1,1,2-Tetrachloroethane	630-20-6	No	42 (6.1)	(C)	8.4 (1.2)	(C)	5.1 (.74)	(C)	3.5 (.51)	(C)	2.6 (.38)	(C)
1,1,2,2-Tetrachloroethane	79-34-5	No	5.5 (.8)	(C)	1.1 (.16)	(C)	.66 (.097)	(C)	.46 (.066)	(C)	.33 (.049)	(C)
Tetrachloroethylene (PCE)	127-18-4	No	52 (7.7)	(C)	10 (1.5)	(C)	6.3 (.93)	(C)	4.3 (.64)	(C)	3.2 (.47)	(C)
Toluene	108-88-3	Yes	5100 (1400) (NC)				5100 (1400) (NC)					
Toxaphene	8001-35-2	No	1 (.13)	(C)	.2 (.027)	(C)	.12 (.016)	(C)	.083 (.011)	(C)	.061 (.0082)	(C)
1,1,1-Trichloroethane	71-55-6	No			2300 (420)	(NC)	2300 (420)	(NC)	2300 (420)	(NC)	2300 (420)	(NC)
1,1,2-Trichloroethane	79-00-5	No	20 (3.6)	(C)	3.9 (.72)	(C)	2.4 (.44)	(C)	1.6 (.3)	(C)	1.2 (.22)	(C)
Trichloroethylene (TCE)	79-01-6	No	20 (3.8)	(C)	4.1 (.75)	(C)	2.5 (.46)	(C)	1.7 (.31)	(C)	1.2 (.23)	(C)
1,2,4-Trimethylbenzene	95-63-6	No			6.2 (1.3)	(NC)	6.2 (1.3)	(NC)	6.2 (1.3)	(NC)	6.2 (1.3)	(NC)
1,3,5-Trimethylbenzene	108-67-8	No			6.2 (1.3)	(NC)	6.2 (1.3)	(NC)	6.2 (1.3)	(NC)	6.2 (1.3)	(NC)
Vinyl acetate	108-05-4	No	89 (25)	(NC)	210 (59)	(NC)	210 (59)	(NC)	210 (59)	(NC)	210 (59)	(NC)
Vinyl chloride (chloroethene)	75-01-4	No	35 (14)	(C)	7.1 (2.8)	(C)	4.3 (1.7)	(C)	2.9 (1.2)	(C)	2.2 (.85)	(C)
Xylene mixed (total)	1330-20-7	Yes	1400 (310) (NC)				110 (24) (NC)					

Appendix VIII – Tables

Table 3
Indoor Air Action Levels - Commercial

Contaminant	CAS	Biodeg?	Sub-Chronic 1 year ug/m³ (ppbv)		Chronic 5 years ug/m³ (ppbv)		10 years ug/m³ (ppbv)		20 years ug/m³ (ppbv)		25 years ug/m³ (ppbv)	
Acetone (2-Propanone)	67-64-1	Yes					4600 (1900) (NC)					
Acrolein	107-02-8	Yes					.029 (.013) (NC)					
Aldrin	309-00-2	No	.15 (.01)	(NC)	.042 (.0028)	(C)	.021 (.0014)	(C)	.011 (.0007)	(C)	.0084 (.00056)	(C)
Benzene	71-43-2	Yes	44 (14) (C)				5.3 (1.7) (C)					
Bis(2-chloro-1-methylethyl) ether	108-60-1	No	100 (15)	(C)	20 (2.9)	(C)	10 (1.5)	(C)	5.1 (.73)	(C)	4.1 (.58)	(C)
Bis(2-Chloroethyl)ether	111-44-4	No	3 (.51)	(C)	.6 (.1)	(C)	.3 (.051)	(C)	.15 (.025)	(C)	.12 (.02)	(C)
Bis(2-chloroisopropyl)ether	39638-32-9	No	100 (15)	(C)	20 (2.9)	(C)	10 (1.5)	(C)	5.1 (.73)	(C)	4.1 (.58)	(C)
Bromodichloromethane	75-27-4	No	58 (8.6)	(C)	12 (1.7)	(C)	5.8 (.86)	(C)	2.9 (.43)	(C)	2.3 (.34)	(C)
Bromoform(tribromomethane)	75-25-2	No	920 (89)	(C)	100 (9.9)	(NC)	92 (8.9)	(C)	46 (4.4)	(C)	37 (3.5)	(C)
n-Butanol	71-36-3	No			13 (4.4)	(NC)	13 (4.4)	(NC)	13 (4.4)	(NC)	13 (4.4)	(NC)
Carbon disulfide	75-15-0	No			1000 (330)	(NC)	1000 (330)	(NC)	1000 (330)	(NC)	1000 (330)	(NC)
Carbon tetrachloride	56-23-5	No	67 (11)	(C)	3.6 (.57)	(NC)	3.6 (.57)	(NC)	3.4 (.54)	(C)	2.7 (.43)	(C)
Chlordane	12789-03-6	No	10 (.61)	(C)	1 (.061)	(NC)	1 (.061)	(NC)	.51 (.03)	(C)	.41 (.024)	(C)
Chlorobenzene	108-90-7	No			87 (19)	(NC)	87 (19)	(NC)	87 (19)	(NC)	87 (19)	(NC)
Chloroethane	75-00-3	No	1200 (470)	(C)	250 (94)	(C)	120 (47)	(C)	62 (23)	(C)	49 (19)	(C)
Chloroform	67-66-3	No	44 (9)	(C)	8.8 (1.8)	(C)	4.4 (.9)	(C)	2.2 (.45)	(C)	1.8 (.36)	(C)
2-Chlorophenol	95-57-8	No	260 (48)	(NC)	26 (4.8)	(NC)	26 (4.8)	(NC)	26 (4.8)	(NC)	26 (4.8)	(NC)
Cyclohexane	110-82-7	No			8700 (2500)	(NC)	8700 (2500)	(NC)	8700 (2500)	(NC)	8700 (2500)	(NC)
DDD	72-54-8	No	15 (1.1)	(C)	3 (.23)	(C)	1.5 (.11)	(C)	.75 (.057)	(C)	.6 (.046)	(C)
1,2-Dibromoethane	106-93-4	No	1.7 (.22)	(C)	.34 (.044)	(C)	.17 (.022)	(C)	.085 (.011)	(C)	.068 (.0089)	(C)
1,2-Dichlorobenzene	95-50-1	No			290 (49)	(NC)	290 (49)	(NC)	290 (49)	(NC)	290 (49)	(NC)
1,3-Dichlorobenzene	541-73-1	No			150 (25)	(NC)	150 (25)	(NC)	150 (25)	(NC)	150 (25)	(NC)
1,4-Dichlorobenzene	106-46-7	No	160 (27)	(C)	33 (5.4)	(C)	16 (2.7)	(C)	8.1 (1.4)	(C)	6.5 (1.1)	(C)
1,1-Dichloroethane	75-34-3	No			720 (180)	(NC)	720 (180)	(NC)	720 (180)	(NC)	720 (180)	(NC)
1,2-Dichloroethane	107-06-2	No	39 (9.7)	(C)	7.2 (1.8)	(NC)	3.9 (.97)	(C)	2 (.49)	(C)	1.6 (.39)	(C)
1,1-Dichloroethylene	75-35-4	No			290 (73)	(NC)	290 (73)	(NC)	290 (73)	(NC)	290 (73)	(NC)
cis-1,2-Dichloroethylene	156-59-2	No			51 (13)	(NC)	51 (13)	(NC)	51 (13)	(NC)	51 (13)	(NC)
trans-1,2-Dichloroethylene	156-60-5	No			100 (26)	(NC)	100 (26)	(NC)	100 (26)	(NC)	100 (26)	(NC)
2,4-Dichlorophenoxyacetic acid (2,4-D)	94-75-7	No			51 (5.7)	(NC)	51 (5.7)	(NC)	51 (5.7)	(NC)	51 (5.7)	(NC)
1,2-Dichloropropane	78-87-5	No	53 (11)	(C)	5.6 (1.2)	(NC)	5.3 (1.1)	(C)	2.6 (.57)	(C)	2.1 (.46)	(C)
1,3-Dichloropropene	542-75-6	No	29 (6.5)	(NC)	29 (6.5)	(NC)	26 (5.7)	(C)	13 (2.8)	(C)	10 (2.3)	(C)

Appendix VIII – Tables

Table 3
Indoor Air Action Levels - Commercial

Contaminant	CAS	Biodeg?	Sub-Chronic		Chronic							
			1 year		5 years		10 years		20 years		25 years	
			ug/m³ (ppbv)		ug/m³ (ppbv)		ug/m³ (ppbv)		ug/m³ (ppbv)		ug/m³ (ppbv)	
N,N Dimethylformamide	68-12-2	No			44 (15)	(NC)	44 (15)	(NC)	44 (15)	(NC)	44 (15)	(NC)
Ethyl acetate	141-78-6	No			4600 (1300)	(NC)	4600 (1300)	(NC)	4600 (1300)	(NC)	4600 (1300)	(NC)
Ethylbenzene	100-41-4	Yes	6300 (1500) (NC)				1500 (340) (NC)					
beta-HCH(beta-BHC)	319-85-7	No	1.9 (.16)	(C)	.38 (.032)	(C)	.19 (.016)	(C)	.094 (.0079)	(C)	.075 (.0063)	(C)
Heptachlor	76-44-8	No	.78 (.051)	(C)	.16 (.01)	(C)	.078 (.0051)	(C)	.039 (.0025)	(C)	.031 (.002)	(C)
Hexachloroethane	67-72-1	No	260 (26)	(C)	5.1 (.53)	(NC)	5.1 (.53)	(NC)	5.1 (.53)	(NC)	5.1 (.53)	(NC)
n-Hexane	110-54-3	No			290 (83)	(NC)	290 (83)	(NC)	290 (83)	(NC)	290 (83)	(NC)
Isopropylbenzene (Cumene)	98-82-8	No			560 (110)	(NC)	560 (110)	(NC)	560 (110)	(NC)	560 (110)	(NC)
Methyl bromide (bromomethane)	74-83-9	No			7.2 (1.8)	(NC)	7.2 (1.8)	(NC)	7.2 (1.8)	(NC)	7.2 (1.8)	(NC)
Methyl ethyl ketone (MEK)	78-93-3	Yes					7200 (2400) (NC)					
Methyl tertiary butyl ether (MTBE)	1634-04–4	No	3900 (1100)	(C)	790 (220)	(C)	390 (110)	(C)	200 (54)	(C)	160 (44)	(C)
4-Methyl-2-pentanone (MIBK)	108-10-1	Yes					4400 (1100) (NC)					
Methylene chloride	75-09-2	No	2200 (640)	(C)	450 (130)	(C)	220 (64)	(C)	110 (32)	(C)	89 (26)	(C)
2-Methylphenol(o-cresol)	95-48-7	No			260 (58)	(NC)	260 (58)	(NC)	260 (58)	(NC)	260 (58)	(NC)
Phenol	108-95-2	Yes					1500 (400) (NC)					
n-Propylbenzene	103-65-1	No			200 (42)	(NC)	200 (42)	(NC)	200 (42)	(NC)	200 (42)	(NC)
Styrene	100-42-5	Yes					1500 (350) (NC)					
1,1,1,2-Tetrachloroethane	630-20-6	No	140 (20)	(C)	28 (4)	(C)	14 (2)	(C)	6.9 (1)	(C)	5.5 (.8)	(C)
1,1,2,2-Tetrachloroethane	79-34-5	No	18 (2.6)	(C)	3.6 (.52)	(C)	1.8 (.26)	(C)	.89 (.13)	(C)	.72 (.1)	(C)
Tetrachloroethylene (PCE)	127-18-4	No	170 (25)	(C)	34 (5)	(C)	17 (2.5)	(C)	8.5 (1.3)	(C)	6.8 (1)	(C)
Toluene	108-88-3	Yes	7200 (1900) (NC)				7200 (1900) (NC)					
Toxaphene	8001-35-2	No	3.3 (.44)	(C)	.65 (.088)	(C)	.33 (.044)	(C)	.16 (.022)	(C)	.13 (.018)	(C)
1,1,1-Trichloroethane	71-55-6	No			3200 (590)	(NC)	3200 (590)	(NC)	3200 (590)	(NC)	3200 (590)	(NC)
1,1,2-Trichloroethane	79-00-5	No	64 (12)	(C)	13 (2.3)	(C)	6.4 (1.2)	(C)	3.2 (.59)	(C)	2.6 (.47)	(C)
Trichloroethylene (TCE)	79-01-6	No	200 (37)	(C)	40 (7.4)	(C)	20 (3.7)	(C)	9.9 (1.8)	(C)	7.9 (1.5)	(C)
1,2,4-Trimethylbenzene	95-63-6	No			8.7 (1.8)	(NC)	8.7 (1.8)	(NC)	8.7 (1.8)	(NC)	8.7 (1.8)	(NC)
1,3,5-Trimethylbenzene	108-67-8	No			8.7 (1.8)	(NC)	8.7 (1.8)	(NC)	8.7 (1.8)	(NC)	8.7 (1.8)	(NC)
Vinyl acetate	108-05-4	No	290 (83)	(NC)	290 (83)	(NC)	290 (83)	(NC)	290 (83)	(NC)	290 (83)	(NC)
Vinyl chloride (chloroethene)	75-01-4	No	220 (86)	(C)	45 (18)	(C)	22 (8.6)	(C)	11 (4.3)	(C)	8.9 (3.5)	(C)
Xylene mixed (total)	1330-20-7	Yes	4400 (1000) (NC)				150 (34) (NC)					

Appendix VIII – Tables

Table 4
Residential Ground Water Screening Levels for Chlorinated Compounds (μg/l)

		Compound											
		Tetrachloroethylene (PCE)			Trichloroethylene (TCE)			1,2-Dichloroethane (1,2-DCA)			Vinyl Chloride (VC)		
		Depth to Ground Water			Depth to Ground Water			Depth to Ground Water			Depth to Ground Water		
Exposure Duration	Soil Type	5ft	10ft	15ft	5ft	10ft	15ft	5ft	10ft	15ft	5ft	10ft	15ft
1 Year	Sand	120	130	160	77	84	99	470	520	610	39	43	51
1 Year	Loamy Sand	260	270	290	170	180	190	1000	1100	1200	87	90	96
1 Year	Sandy Loam	630	640	660	400	410	420	2500	2500	2600	210	210	220
1 Year	Loam	1000	1100	1100	650	680	700	4000	4200	4300	330	350	360
5 Year	Sand	23	25	30	16	17	20	95	100	120	8	8.8	10
5 Year	Loamy Sand	51	53	56	35	36	38	210	220	230	18	18	20
5 Year	Sandy Loam	120	120	130	82	84	86	500	510	520	42	43	44
5 Year	Loam	200	200	210	130	140	140	800	830	870	68	70	73
10 Year	Sand	15	16	19	9.6	11	12	59	65	77	4.8	5.3	6.3
10 Year	Loamy Sand	32	33	36	21	22	23	130	140	140	11	11	12
10 Year	Sandy Loam	76	78	80	50	51	53	310	320	330	25	26	27
10 Year	Loam	120	130	130	81	84	88	500	520	540	41	43	44
20 Year	Sand	9.9	11	13	6.5	7.2	8.4	40	43	51	3.3	3.6	4.2
20 Year	Loamy Sand	22	23	24	14	15	16	87	91	97	7.2	7.5	8
20 Year	Sandy Loam	52	53	55	34	35	36	210	210	220	17	18	18
20 Year	Loam	84	87	91	55	57	60	330	350	360	28	29	30
30 Year	Sand	7.4	8.1	9.6	4.6	5.1	6	29	32	38	2.5	2.7	3.2
30 Year	Loamy Sand	16	17	18	10	11	11	64	67	71	5.5	5.7	6.1
30 Year	Sandy Loam	39	40	41	24	25	25	150	160	160	13	13	14
30 Year	Loam	62	65	68	39	41	42	250	260	270	21	22	23

Table 5
Commercial Ground Water Screening Levels for Chlorinated Compounds (μg/l)

Compound: Tetrachloroethylene (PCE); Trichloroethylene (TCE); 1,2-Dichloroethane (1,2-DCA); Vinyl Chloride (VC)

Exposure Duration: 1 Year

Soil Type	PCE 1 Year – Depth to Ground Water			TCE 1 Year – Depth to Ground Water			1,2-DCA 1 Year – Depth to Ground Water			VC 1 Year – Depth to Ground Water		
	5ft	10ft	15ft	5ft	10ft	15ft	5ft	10ft	15ft	5ft	10ft	15ft
Sand	390	430	510	770	840	990	1500	1700	2000	250	270	320
Loamy Sand	860	900	960	1700	1800	1900	3400	3500	3800	550	570	610
Sandy Loam	2100	2100	2200	4000	4100	4200	8100	8300	8500	1300	1300	1400
Loam	3300	3500	3600	6500	6800	7000	13000	14000	14000	2100	2200	2300

Exposure Duration: 5 Year

Soil Type	PCE 5 Year – Depth to Ground Water			TCE 5 Year – Depth to Ground Water			1,2-DCA 5 Year – Depth to Ground Water			VC 5 Year – Depth to Ground Water		
	5ft	10ft	15ft	5ft	10ft	15ft	5ft	10ft	15ft	5ft	10ft	15ft
Sand	78	86	100	150	170	200	280	310	370	51	56	66
Loamy Sand	170	180	190	340	350	380	630	650	700	110	120	120
Sandy Loam	410	420	430	800	820	840	1500	1500	1600	270	270	280
Loam	660	690	720	1300	1400	1400	2400	2500	2600	430	450	460

Exposure Duration: 10 Year

Soil Type	PCE 10 Year – Depth to Ground Water			TCE 10 Year – Depth to Ground Water			1,2-DCA 10 Year – Depth to Ground Water			VC 10 Year – Depth to Ground Water		
	5ft	10ft	15ft	5ft	10ft	15ft	5ft	10ft	15ft	5ft	10ft	15ft
Sand	39	43	51	77	84	99	150	170	200	25	27	32
Loamy Sand	86	90	96	170	180	190	340	350	380	55	57	61
Sandy Loam	210	210	220	400	410	420	810	830	850	130	130	140
Loam	330	350	360	650	680	700	1300	1400	1400	210	220	230

Exposure Duration: 20 Year

Soil Type	PCE 20 Year – Depth to Ground Water			TCE 20 Year – Depth to Ground Water			1,2-DCA 20 Year – Depth to Ground Water			VC 20 Year – Depth to Ground Water		
	5ft	10ft	15ft	5ft	10ft	15ft	5ft	10ft	15ft	5ft	10ft	15ft
Sand	20	22	25	38	42	49	79	87	100	12	14	16
Loamy Sand	43	45	48	84	87	93	170	180	190	27	28	30
Sandy Loam	100	110	110	200	200	210	410	420	430	65	66	68
Loam	170	170	180	320	330	350	670	700	720	100	110	110

Exposure Duration: 25 Year

Soil Type	PCE 30 Year – Depth to Ground Water			TCE 30 Year – Depth to Ground Water			1,2-DCA 30 Year – Depth to Ground Water			VC 30 Year – Depth to Ground Water		
	5ft	10ft	15ft	5ft	10ft	15ft	5ft	10ft	15ft	5ft	10ft	15ft
Sand	16	17	20	30	33	39	63	70	82	10	11	13
Loamy Sand	35	36	38	67	69	74	140	140	150	22	23	25
Sandy Loam	82	84	86	160	160	170	330	340	350	53	54	55
Loam	130	140	140	260	270	280	540	560	580	85	88	92

Appendix VIII – Tables

Table 6
Soil Screening Levels for Chlorinated Compounds (mg/kg)

Residential

Residential		Exposure Duration 1yr	5yr	10yr	20yr	30yr
Compound	TCE	25	5	5	5	5
	PCE	25	5	5	5	5
	VC	3	1	1	1	1
	1,2 DCA	20	5	5	5	5

Commercial

Comercial		Exposure Duration 1yr	5yr	10yr	20yr	25yr
Compound	TCE	60	10	10	5	5
	PCE	60	10	10	5	5
	VC	8	2	1	1	1
	1,2 DCA	50	10	10	5	5

* The Soil Screening Level for PCE is capped by the RISC Soil Saturation Limit (C_{sat})

Appendix VIII – Tables

Table 7
Residential Screening Levels for Chlorinated Compounds

Sub-Slab

Prompt Action Level

Compound (Prompt Sub-Slab)	Units	1 yr	5 yr	10 yr	20yr	30yr
1,2 DCA	ug/m^3	120	24	15	10	7.4
	ppbv	30	5.9	3.7	2.5	1.8
PCE	ug/m^3	520	100	63	43	32
	ppbv	77	15	9.3	6.3	4.7
TCE	ug/m^3	200	41	25	17	12
	ppbv	37	7.6	4.7	3.2	2.2
VC	ug/m^3	350	71	43	29	22
	ppbv	140	28	17	11	8.6

Potential Chronic Level

Compound (Potential Sub-Slab)	Units	1 yr	5 yr	10 yr	20yr	30yr
1,2 DCA	ug/m^3	7.4-120	7.4-24	7.4-15	7.4-10	7.4
	ppbv	1.8-30	1.8-5.9	1.8-3.7	1.8-2.5	1.8
PCE	ug/m^3	32-520	32-100	32-63	32-43	32
	ppbv	4.7-77	4.7-15	4.7-9.3	4.7-6.3	4.7
TCE	ug/m^3	12-200	12-41	12-25	12-17	12
	ppbv	2.2-37	2.2-7.6	2.2-4.7	2.2-3.2	2.2
VC	ug/m^3	22-350	22-71	22-43	22-29	22
	ppbv	8.6-140	8.6-28	8.6-17	8.6-11	8.6

Crawl Space

Prompt Action Level

Compound (Prompt Crawl Space)	Units	1 yr	5 yr	10 yr	20yr	30yr
1,2 DCA	ug/m^3	12	2.4	1.5	1	0.74
	ppbv	3	0.59	0.37	0.25	0.18
PCE	ug/m^3	52	10	6.3	4.3	3.2
	ppbv	7.7	1.5	0.93	0.63	0.47
TCE	ug/m^3	20	4.1	2.5	1.7	1.2
	ppbv	3.7	0.76	0.47	0.32	0.22
VC	ug/m^3	35	7.1	4.3	2.9	2.2
	ppbv	14	2.8	1.7	1.1	0.86

Potential Chronic Level

Compound (Potential Crawl Space)	Units	1 yr	5 yr	10 yr	20yr	30yr
1,2 DCA	ug/m^3	0.74-12	0.74-2.4	0.74-1.5	0.74-1	0.74
	ppbv	0.18-3	0.18-0.59	0.18-0.37	0.18-0.25	0.18
PCE	ug/m^3	3.2-52	3.2-10	3.2-6.3	3.2-4.3	3.2
	ppbv	0.47-7.7	0.47-1.5	0.47-0.93	0.47-0.63	0.47
TCE	ug/m^3	1.2-20	1.2-4.1	1.2-2.5	1.2-1.7	1.2
	ppbv	0.22-3.7	0.22-0.76	0.22-0.47	0.22-0.32	0.22
VC	ug/m^3	2.2-35	2.2-7.1	2.2-4.3	2.2-2.9	2.2
	ppbv	0.86-14	0.86-2.8	0.86-1.7	0.86-1.1	0.86

Soil Gas

Prompt Action Level

Compound (Prompt Soil Gas)	Units	1 yr	5 yr	10 yr	20yr	30yr
1,2 DCA	ug/m^3	1200	240	150	100	74
	ppbv	300	59	37	25	18
PCE	ug/m^3	5200	1000	630	430	320
	ppbv	770	150	93	63	47
TCE	ug/m^3	2000	410	250	170	120
	ppbv	370	76	47	32	22
VC	ug/m^3	3500	710	430	290	220
	ppbv	1400	280	170	110	86

Potential Chronic Level

Compound (Potential Soil Gas)	Units	1 yr	5 yr	10 yr	20yr	30yr
1,2 DCA	ug/m^3	74-1200	74-240	74-150	74-100	74
	ppbv	18-300	18-59	18-37	18-25	18
PCE	ug/m^3	320-5200	320-1000	320-630	320-430	320
	ppbv	47-770	47-150	47-93	47-63	47
TCE	ug/m^3	120-2000	120-410	120-250	120-170	120
	ppbv	22-370	22-76	22-47	22-32	22
VC	ug/m^3	220-3500	220-710	220-430	220-290	220
	ppbv	86-1400	86-280	86-170	86-110	86

Appendix VIII – Tables

Table 8
Commercial Screening Levels for Chlorinated Compounds

Prompt Action Level

Sub-Slab

Prompt Sub-Slab		Exposure Duration 1 yr	5 yr	10 yr	20yr	25yr
1,2 DCA	ug/m³	390	72	39	20	16
	ppbv	96	18	9.6	4.9	4
PCE	ug/m³	1700	340	170	85	68
	ppbv	250	50	25	13	10
TCE	ug/m³	2000	400	200	99	79
	ppbv	370	74	37	18	15
VC	ug/m³	2200	450	220	110	89
	ppbv	860	180	86	43	35

Crawl Space

Prompt Crawl Space		Exposure Duration 1 yr	5 yr	10 yr	20yr	25yr
1,2 DCA	ug/m³	39	7.2	3.9	2	1.6
	ppbv	9.6	1.8	0.96	0.49	0.4
PCE	ug/m³	170	34	17	8.5	6.8
	ppbv	25	5	2.5	1.3	1
TCE	ug/m³	200	40	20	9.9	7.9
	ppbv	37	7.4	3.7	1.8	1.5
VC	ug/m³	220	45	22	11	8.9
	ppbv	86	18	8.6	4.3	3.5

Soil Gas

Prompt Soil Gas		Exposure Duration 1 yr	5 yr	10 yr	20yr	25yr
1,2 DCA	ug/m³	3900	720	390	200	160
	ppbv	960	180	96	49	40
PCE	ug/m³	17000	3400	1700	850	680
	ppbv	2500	500	250	130	100
TCE	ug/m³	20000	4000	2000	990	790
	ppbv	3700	740	370	180	150
VC	ug/m³	22000	4500	2200	1100	890
	ppbv	8600	1800	860	430	350

Potential Chronic Level

Sub-Slab

Potential Sub-Slab		Exposure Duration 1 yr	5 yr	10 yr	20yr	25yr
1,2 DCA	ug/m³	16-390	16-72	16-39	16-20	16
	ppbv	4-96	4-18	4-9.6	4-4.9	4
PCE	ug/m³	68-1700	68-340	68-170	68-85	68
	ppbv	10-250	10-50	10-25	10-13	10
TCE	ug/m³	79-2000	79-400	79-200	79-99	79
	ppbv	15-370	15-74	15-37	15-18	15
VC	ug/m³	89-2200	89-450	89-220	89-110	89
	ppbv	35-860	35-180	35-86	35-43	35

Crawl Space

Potential Crawl Space		Exposure Duration 1 yr	5 yr	10 yr	20yr	25yr
1,2 DCA	ug/m³	1.6-39	1.6-7.2	1.6-3.9	1.6-2	1.6
	ppbv	0.4-9.6	0.4-1.8	0.4-0.96	0.4-0.49	0.4
PCE	ug/m³	6.8-170	6.8-34	6.8-17	6.8-8.5	6.8
	ppbv	1-25	1-5	1-2.5	1-1.3	1
TCE	ug/m³	7.9-200	7.9-40	7.9-20	7.9-9.9	7.9
	ppbv	1.5-37	1.5-7.4	1.5-3.7	1.5-1.8	1.5
VC	ug/m³	8.9-220	8.9-45	8.9-22	8.9-11	8.9
	ppbv	3.5-86	3.5-18	3.5-8.6	3.5-4.3	3.5

Soil Gas

Potential Soil Gas		Exposure Duration 1 yr	5 yr	10 yr	20yr	25yr
1,2 DCA	ug/m³	160-3900	160-720	160-390	160-200	160
	ppbv	40-960	40-180	40-96	40-49	40
PCE	ug/m³	680-17000	680-3400	680-1700	680-850	680
	ppbv	100-2500	100-500	100-250	100-130	100
TCE	ug/m³	790-20000	790-4000	790-2000	790-990	790
	ppbv	150-3700	150-740	150-370	150-180	150
VC	ug/m³	890-22000	890-4500	890-2200	890-1100	890
	ppbv	350-8600	350-1800	350-860	350-430	350

Appendix IX

References

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References

API, 2004. Collecting and Interpreting Soil Gas Samples from the Vadose Zone: A Practical Strategy for Assessing the Subsurface-Vapor-to-Indoor-Air Migration Pathway at Petroleum Hydrocarbon Sites. American Petroleum Institute, Final Draft, October, 2004.

Commonwealth of Massachusetts, 2002. Indoor Air Sampling and Evaluation Guide. Office of Research and Standards, Department of Environmental Protection, WEC Policy #02-430.

DiGiulio (1). Standard Operating Procedure (SOP) for Installation of Sub-Slab Vapor Probes and Sampling Using EPA Method TO-15 to Support Vapor Intrusion Investigations. U. S. EPA, Office of Research and Development, Draft, (undated).

DiGiulio (2). Assessment of Vapor Intrusion Using Sub-Slab Air Samples; 1. Guidelines for Installation and Sampling of Sub-Slab Vapor Probes. Draft, (undated).

EPA, 1994. Radon Mitigation Standards. Office of Air and Radiation, Office of Radiation and Indoor Air Indoor Environments Division (6609J), EPA 402-R-93-078, October 1993 (Revised April 1994).

EPA, 1997. Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air Second Edition, Determination of Volatile Organic Compounds (VOCs) in Ambient Air Using Specially Prepared Canisters with Subsequent Analysis by Gas Chromatography. EPA Office of Research and Development, EPA/625/R-96/010b.

EPA, 1999. Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air Second Edition, Determination of Volatile Organic Compounds (VOCs) in Ambient Air Using Specially Prepared Canisters and Analyzed by Gas Chromatography/Mass Spectrometry (GC/MS). EPA Office of Research and Development, EPA/625/R-96/010b.

EPA, 2001. Building Radon Out. EPA/402-K-01-002.

EPA, 2002. Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater and Soils. Available on the internet at: http://www.epa.gov/correctiveaction/eis/vapor.htm

EPA, 2003. Consumer's Guide to Radon Reduction. Office of Air and Radiation, Office of Radiation and Indoor Air (6609J), EPA/402-K-03-002, Revised February 2003.

EPA, 2006. Assessment of Vapor Intrusion in Homes Near the Raymark Superfund Site Using Basement and Sub-Slab Air Samples. EPA Office of Research and Development, EPA/600/R-05/147.

Hartman, 2004. How to Collect Reliable Soil-Gas Data for Risk-Based Applications – Specifically Vapor Intrusion. Part 3 – Answers to Frequently Asked Questions. LUSTLine Bulletin 48, November 2004.

IDEM, 2001. Risk Integrated System of Closure; Technical Resource Guidance Document. Indiana Department of Environmental Management, February 15, 2001.

State of California, 2003. State of California Advisory – Active Soil Gas Investigations. Department of Toxic Substances Control and California Regional Water Quality Control Board, Los Angeles Region. January 28, 2003

State of California. 2005. Interim Final: Guidance for the Evaluation and Mitigation of Subsurface Vapor Intrusion to Indoor Air. Department of Toxic Substances Control, California Environmental Protection Agency, December 15, 2004 (Revised February 7, 2005).

State of Colorado. 2004. Indoor Air Guidance. Colorado Department of Public Health and Environment, Hazardous Materials and Waste Management Division. September 2004.

State of New Jersey. 2005. Draft Vapor Intrusion Guidance. New Jersey Department of Environmental Protection. June 2005.